

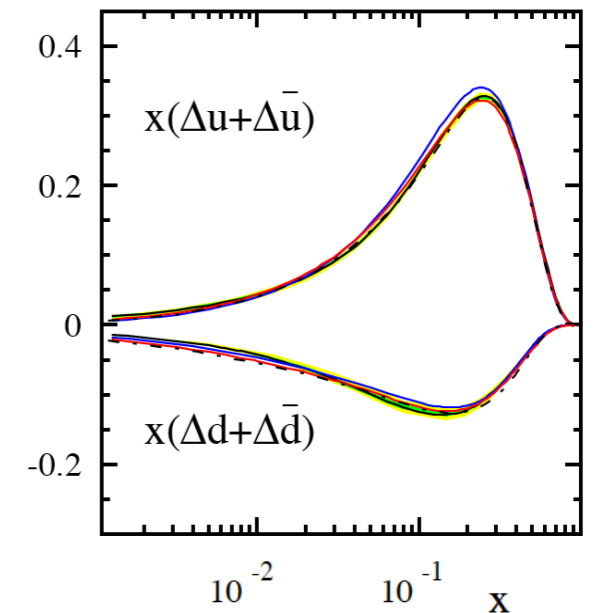
# Measurement of longitudinal single spin asymmetry of $W^{\pm} \rightarrow \mu^{\pm}$ at forward/backward rapidities with PHENIX at $\sqrt{s} = 500 - 510$ GeV polarized p+p collisions

Hideyuki Oide (University of Tokyo / RIKEN)  
on behalf of PHENIX collaboration

# Introduction

Decomposing the spin of the proton w/ parton picture

$$\frac{1}{2} = \underbrace{\frac{1}{2} \sum_f (\Delta q_f + \Delta \bar{q}_f)}_{\substack{\sim 25\% \text{ in total (DIS)} \\ \text{("The spin crisis")}}} + \underbrace{\Delta g}_{\substack{\text{Revealing to be small (RHIC)}}} + \underbrace{L}_{\substack{\text{no measurements} \\ \text{Needs more precision (SIDIS)}}}$$



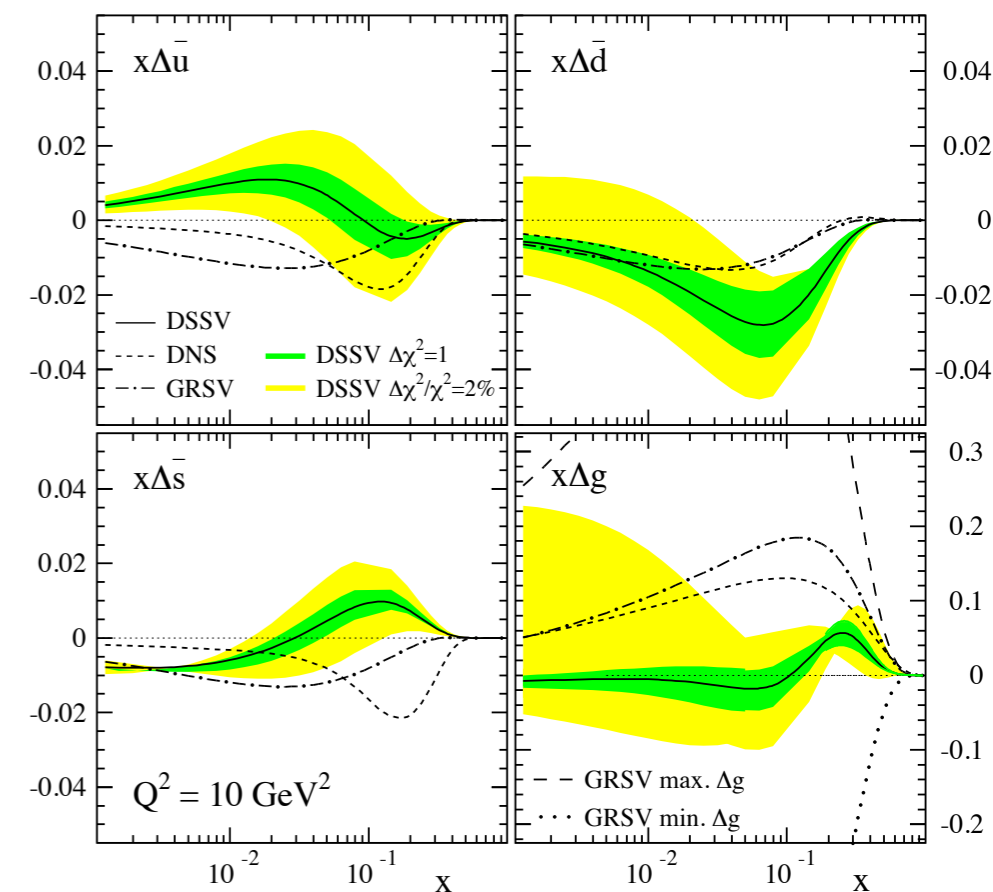
Looking into the detail of quark flavor...

$$\underbrace{\Delta u + \Delta \bar{u}}_{\text{sum is known}} + \underbrace{\Delta d + \Delta \bar{d}}_{\text{sum is known}} + \underbrace{\Delta s + \Delta \bar{s}}_{\substack{\text{suggested sum} < 0 \\ \text{the same shape?} \\ \text{node in mid } x?}}$$

isospin asymmetric?

Flavor-separating measurements of sea quark's polarized PDF have been desired.

Phys. Rev. D80 (2009) 034030



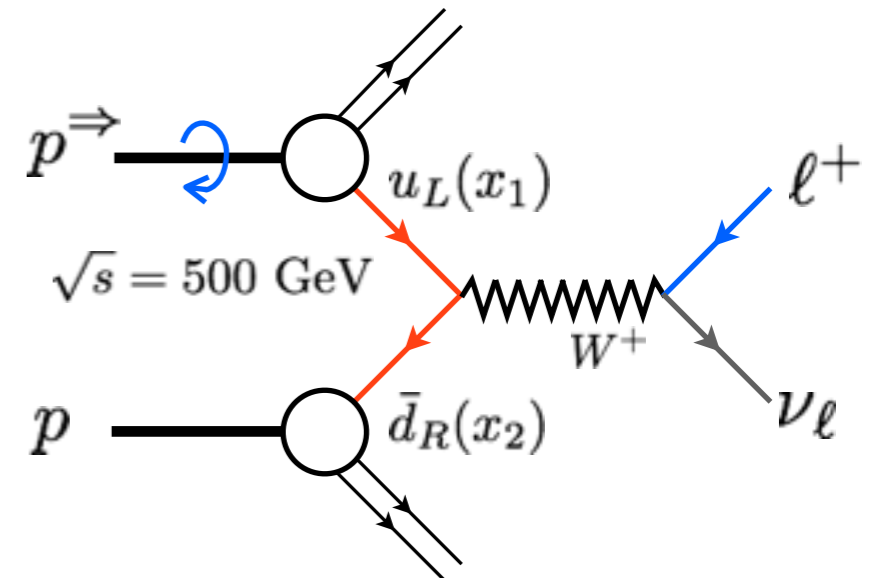
# Probing sea quark via $W^\pm \rightarrow \ell^\pm$

Longitudinally polarized p+p at  $\sqrt{s} = 500$  (510) GeV at RHIC

Single Spin Asymmetry of W production  
via **parity violating** weak coupling

$$A_L = \frac{d\sigma^{\Rightarrow} - d\sigma^{\Leftarrow}}{d\sigma^{\Rightarrow} + d\sigma^{\Leftarrow}}$$

is a **flavor-sensitive** probe to sea quark polarization.



$$d\sigma(p^{\Rightarrow}p \rightarrow W^+) \propto u_L^{\Rightarrow}(x_1)\bar{d}_R(x_2) + \bar{d}_R^{\Rightarrow}(x_1)u_L(x_2)$$

**PHENIX** : suitable for **leptonic decays** of W

- Central Arm:

$$W^\pm \rightarrow e^\pm, \quad |\eta| < 0.35 \quad (\text{next talk})$$

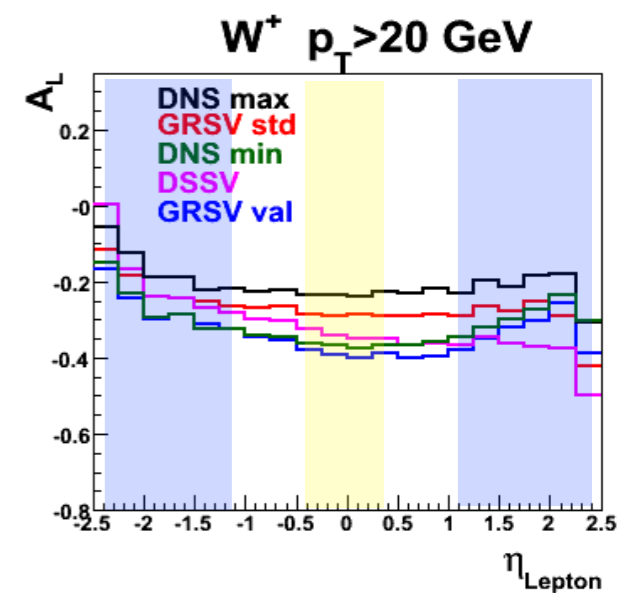
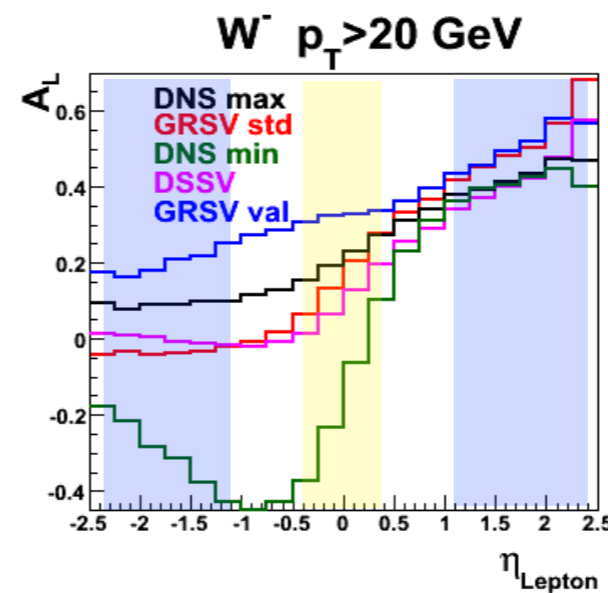
- Forward Muon Arms:

$$W^\pm \rightarrow \mu^\pm$$

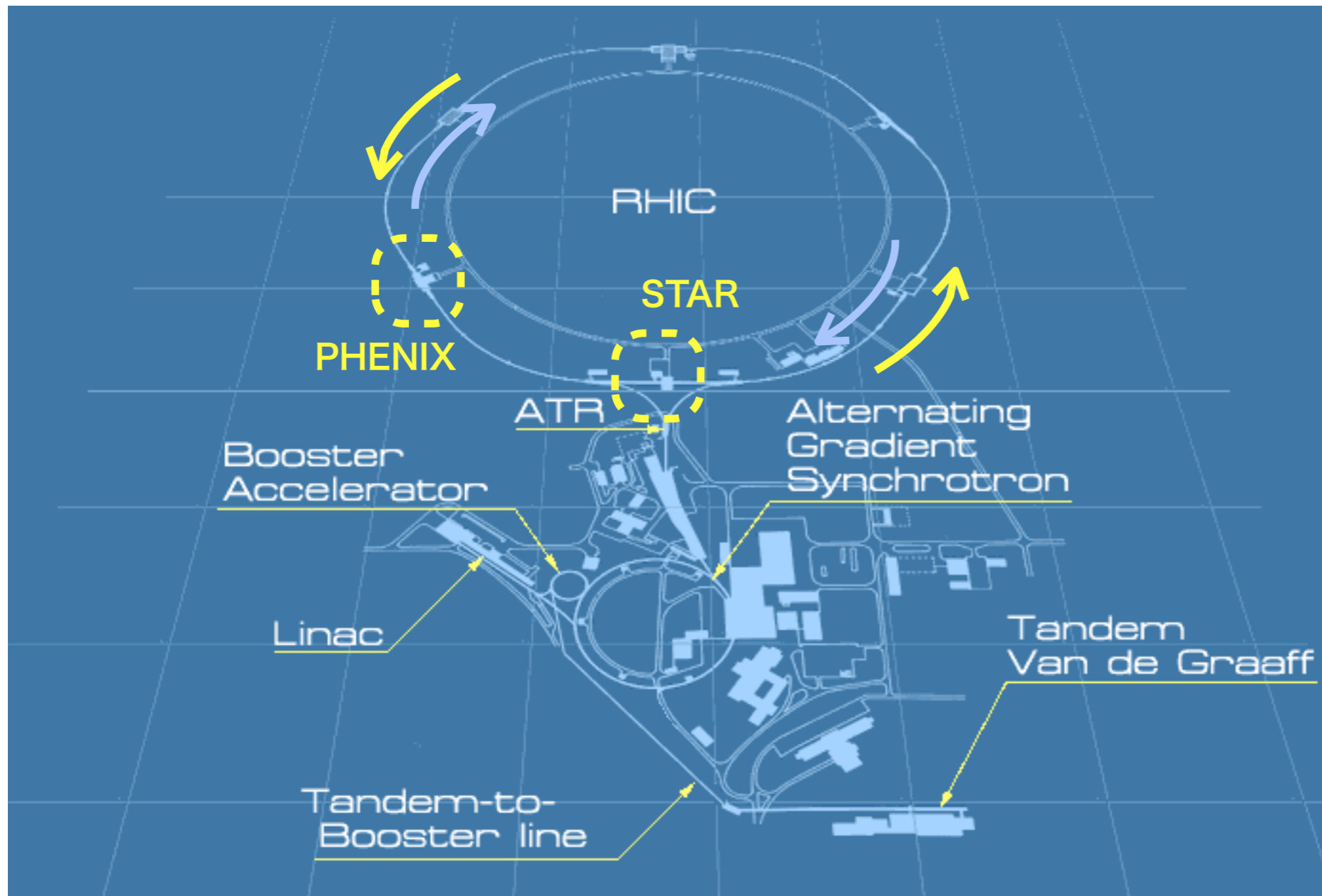
$$-2.2 < \eta < -1.2, \quad 1.2 < \eta < 2.4$$

via measuring single lepton's pT and rapidity

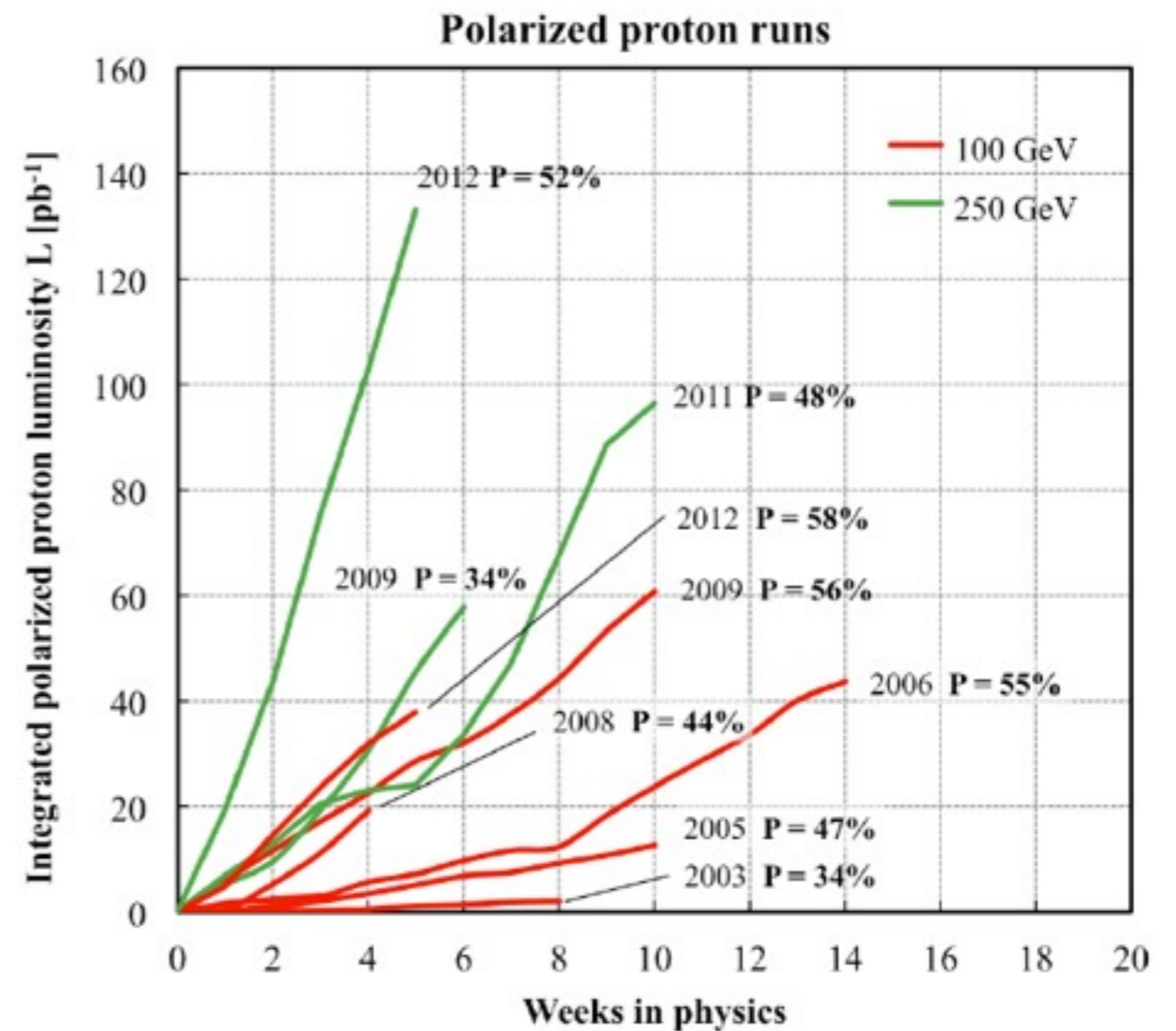
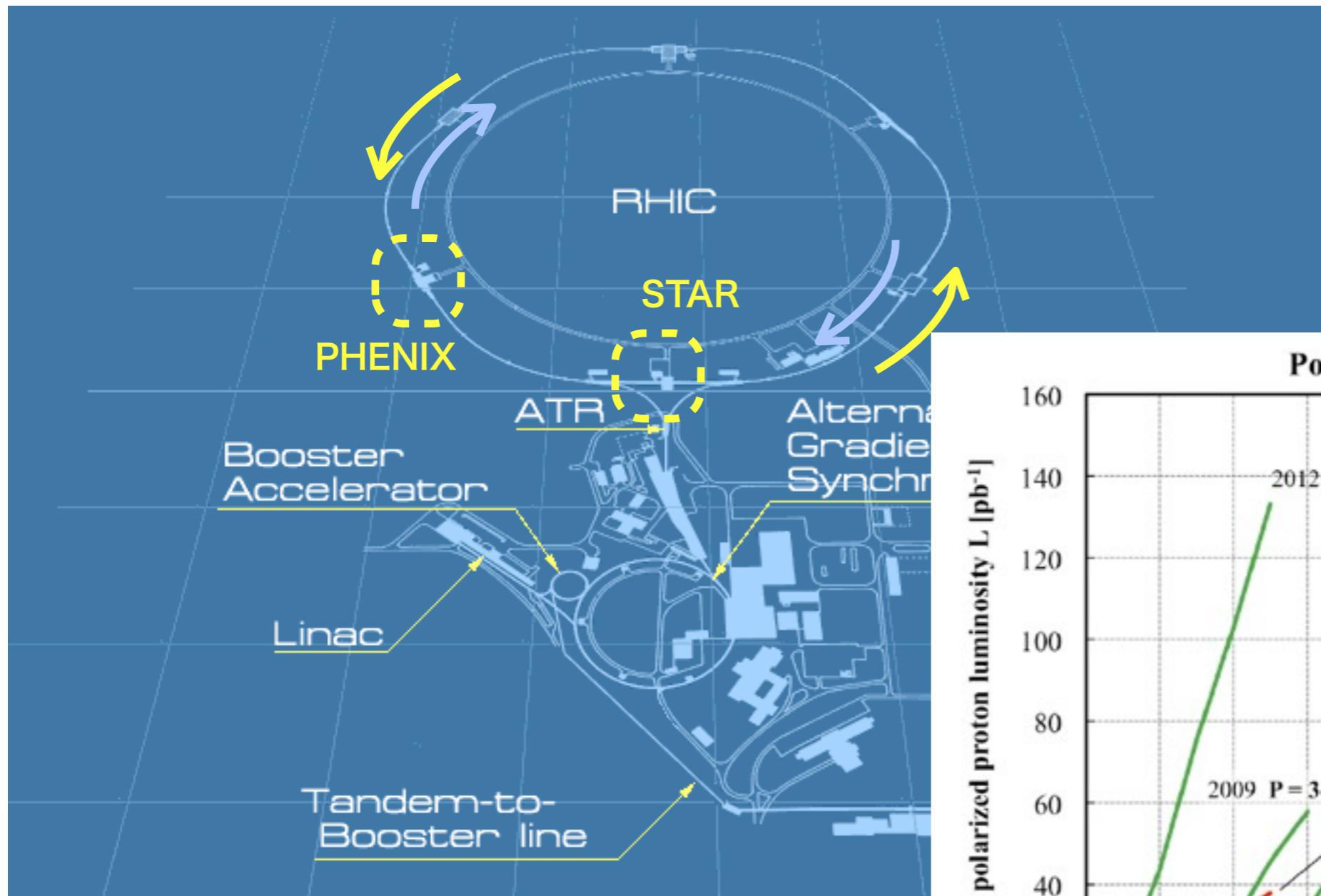
⇒ Various rapidity regions covered.



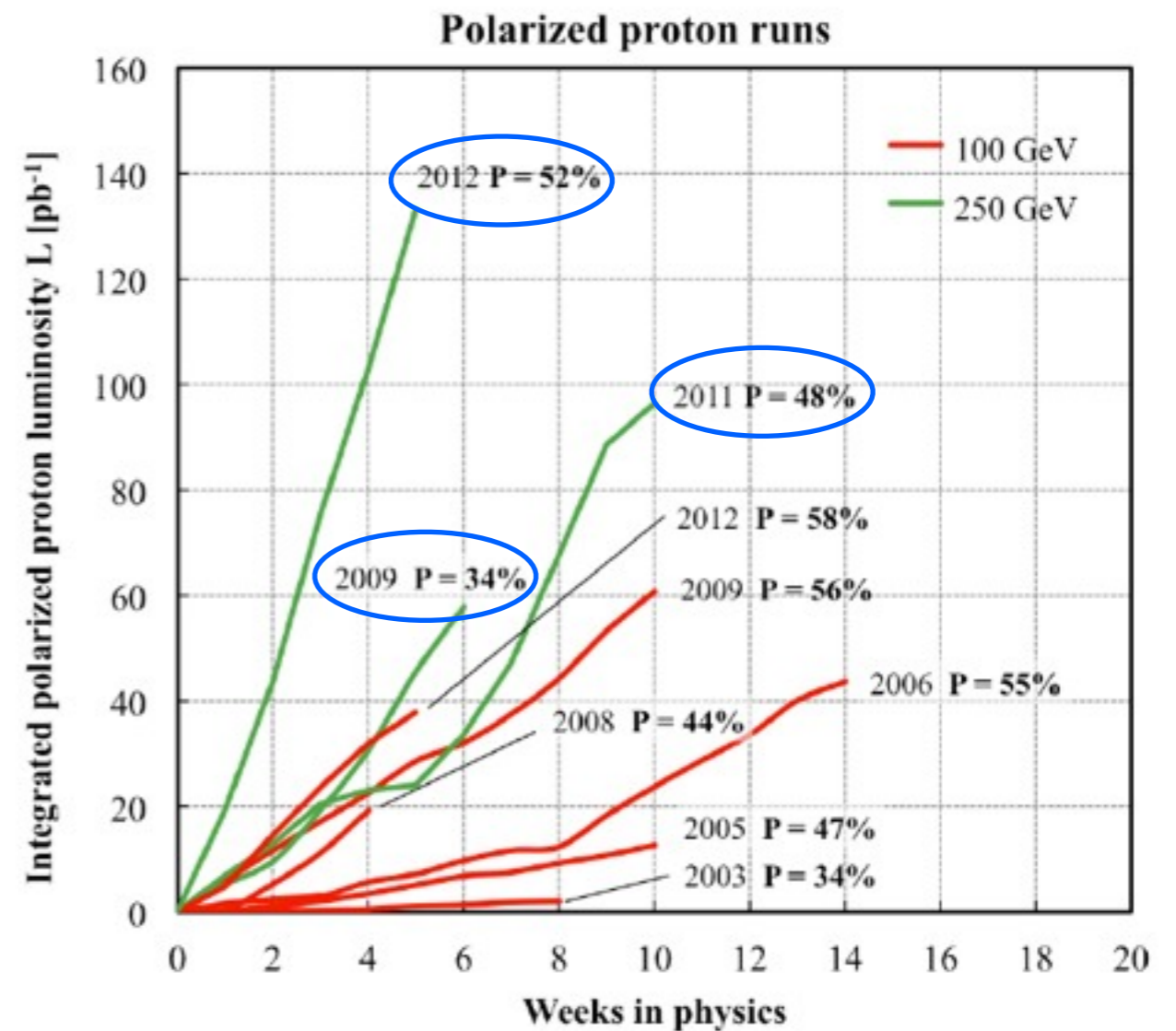
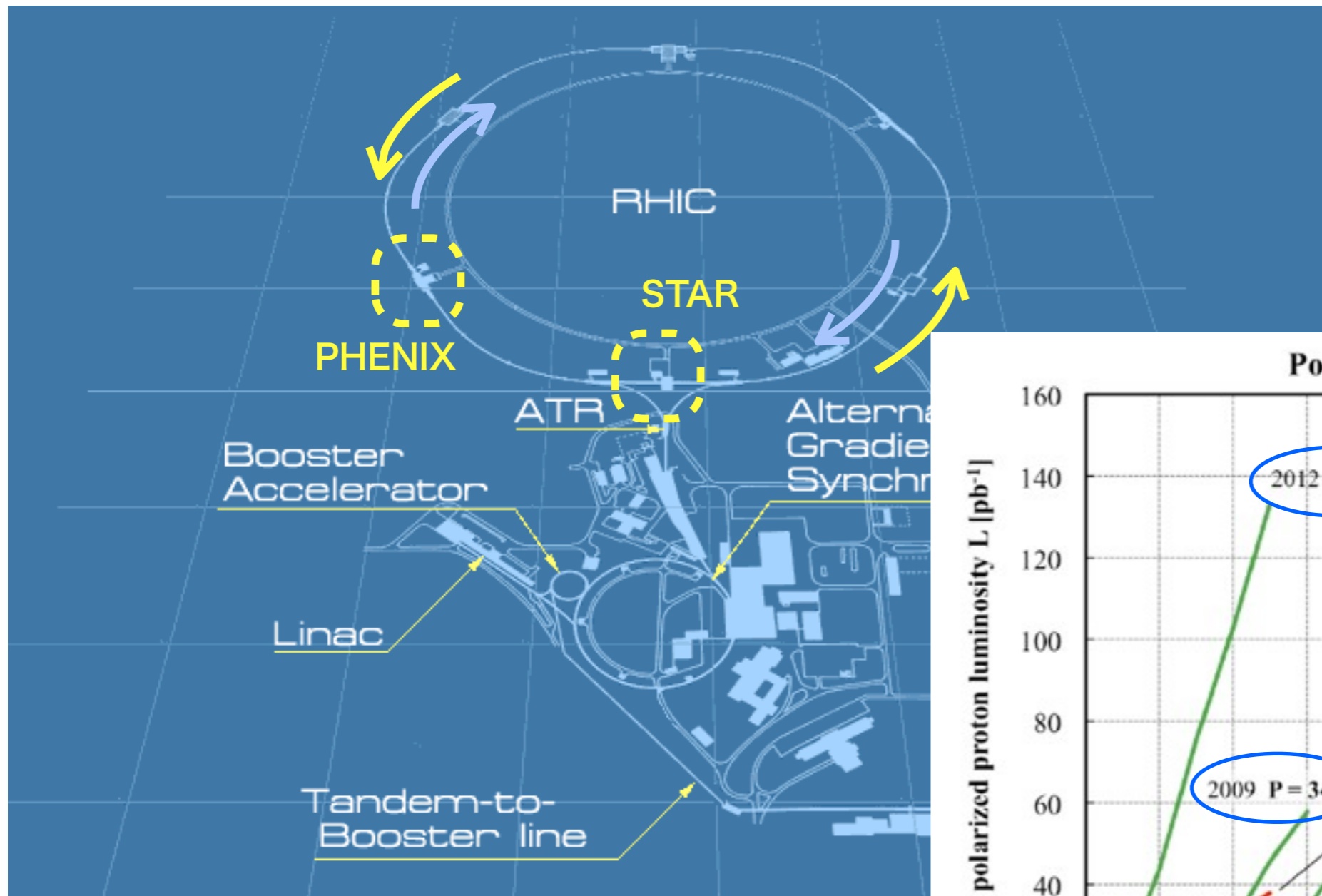
# RHIC



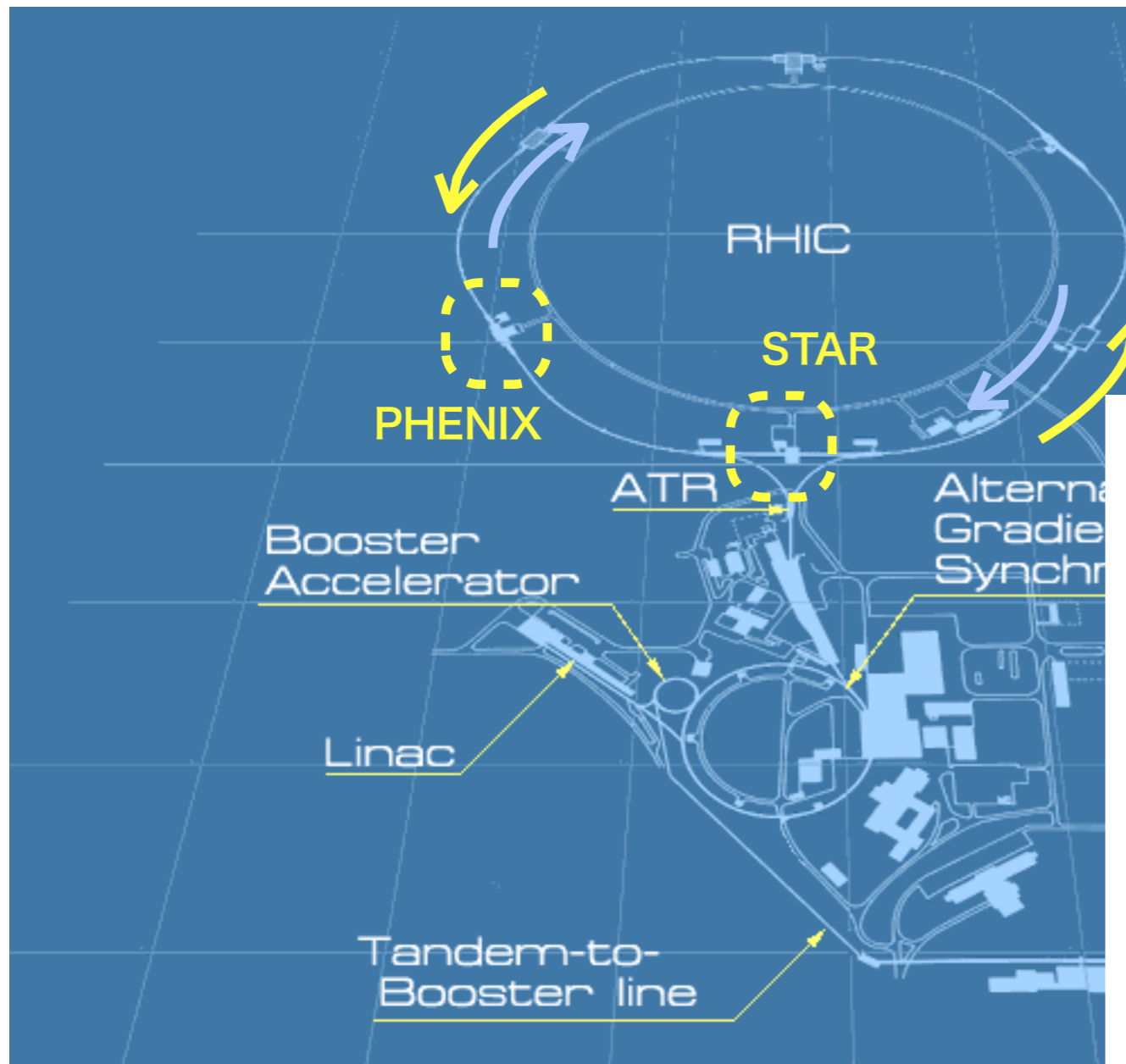
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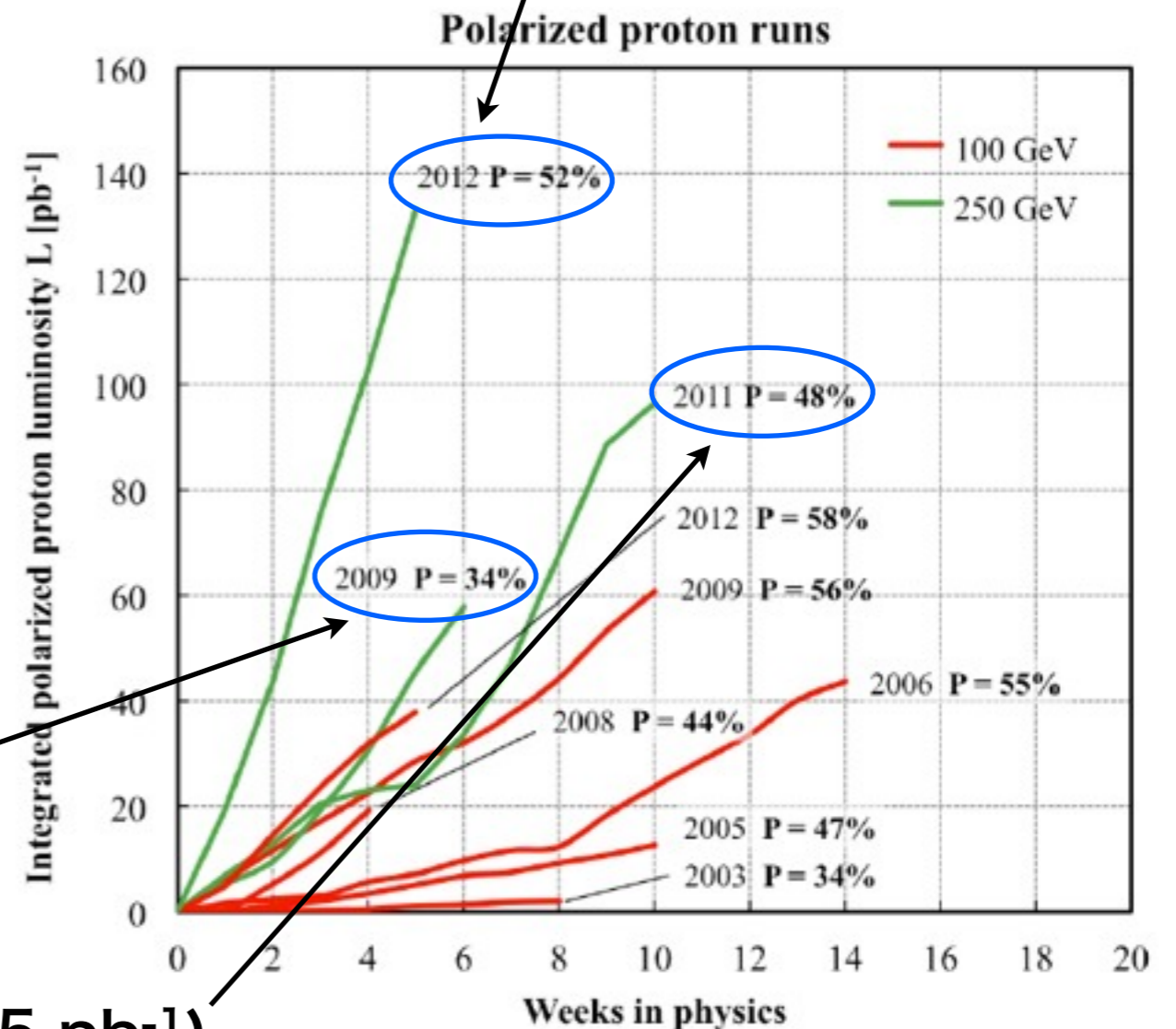
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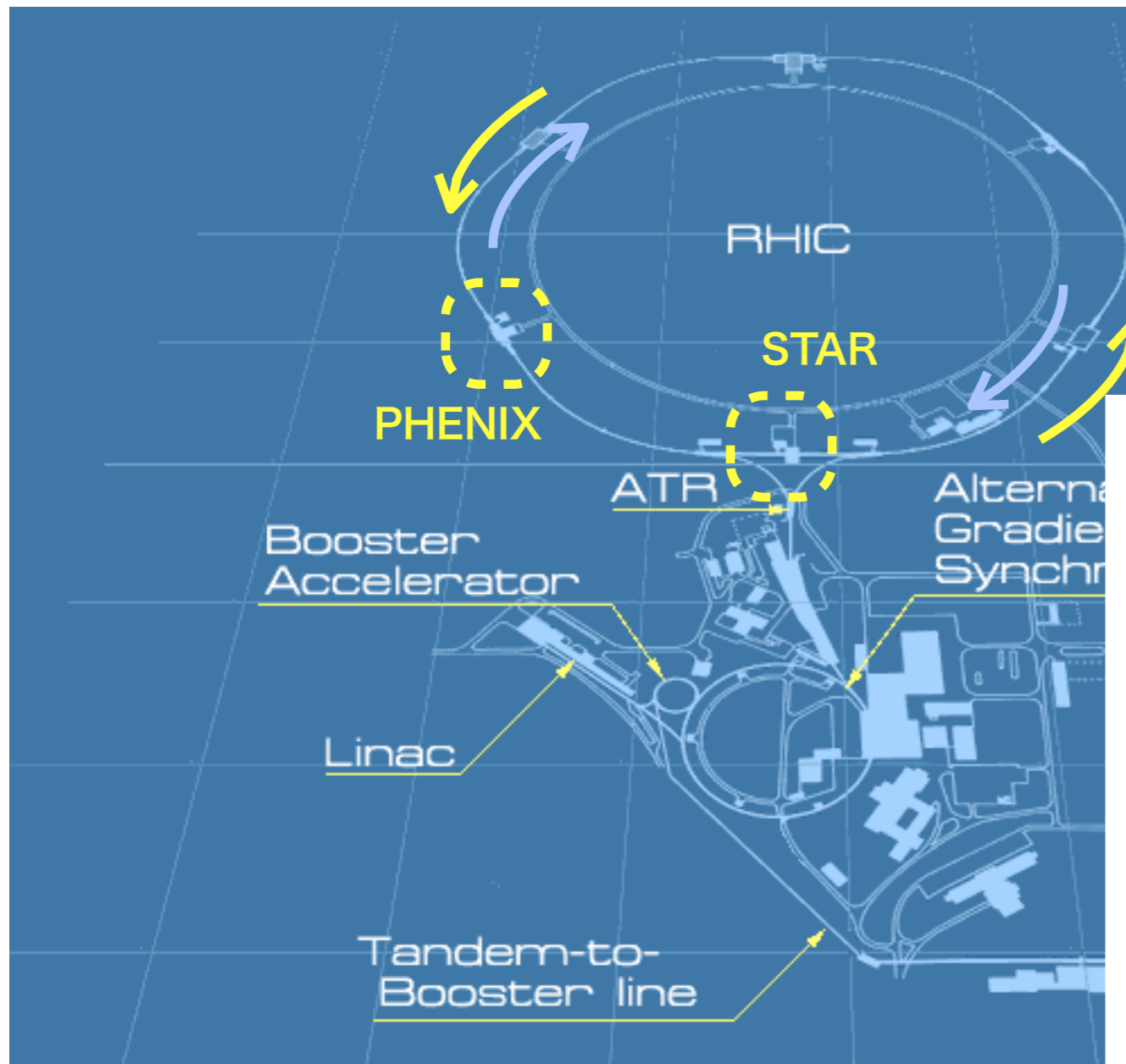
2012: 510 GeV,  $\sim 50 \text{ pb}^{-1}$  (fw)



2009: First Central  $W \rightarrow e$  ( $8.6 \text{ pb}^{-1}$ )

2011: First Forward  $W \rightarrow \mu$  ( $25 \text{ pb}^{-1}$ )

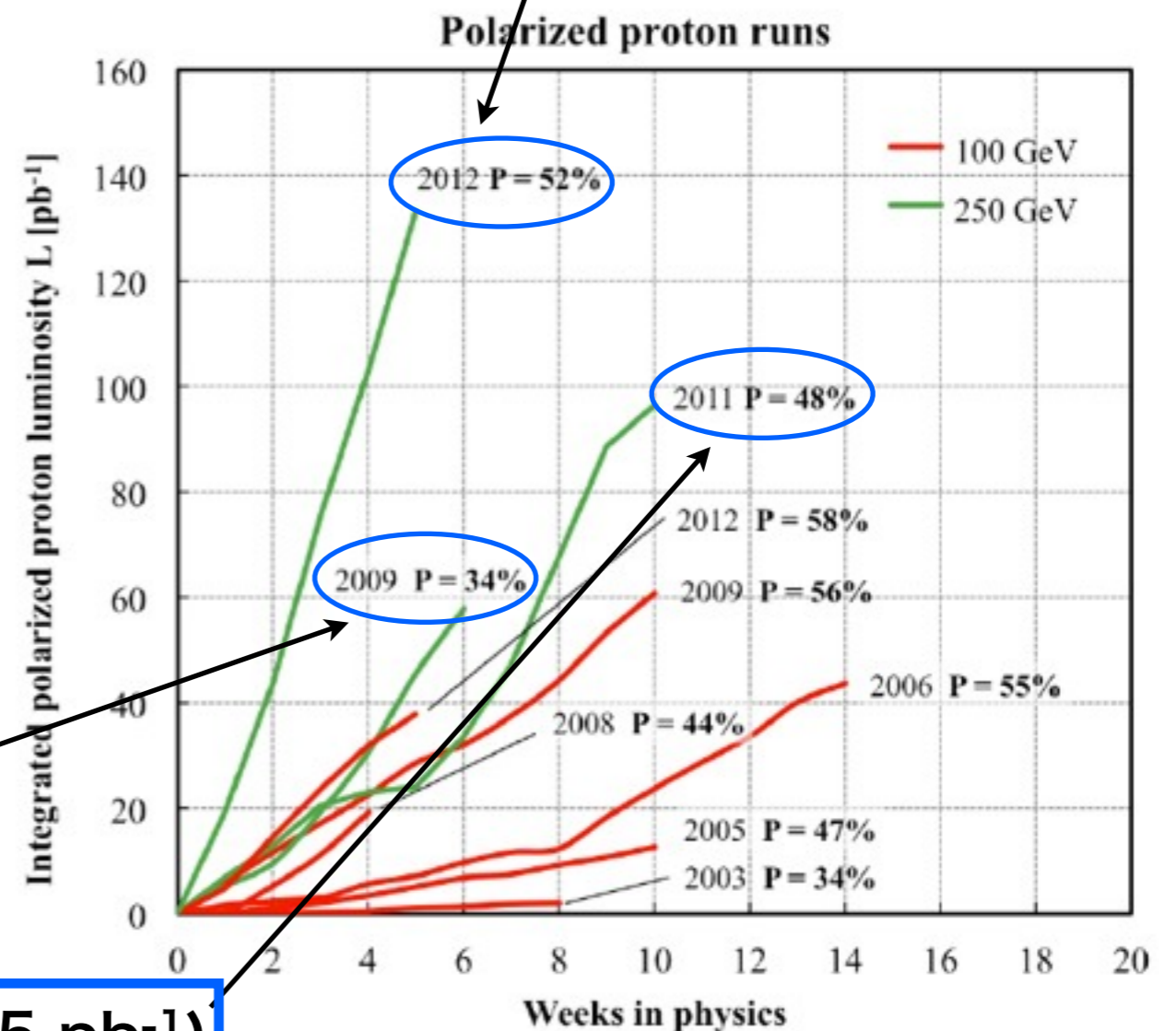
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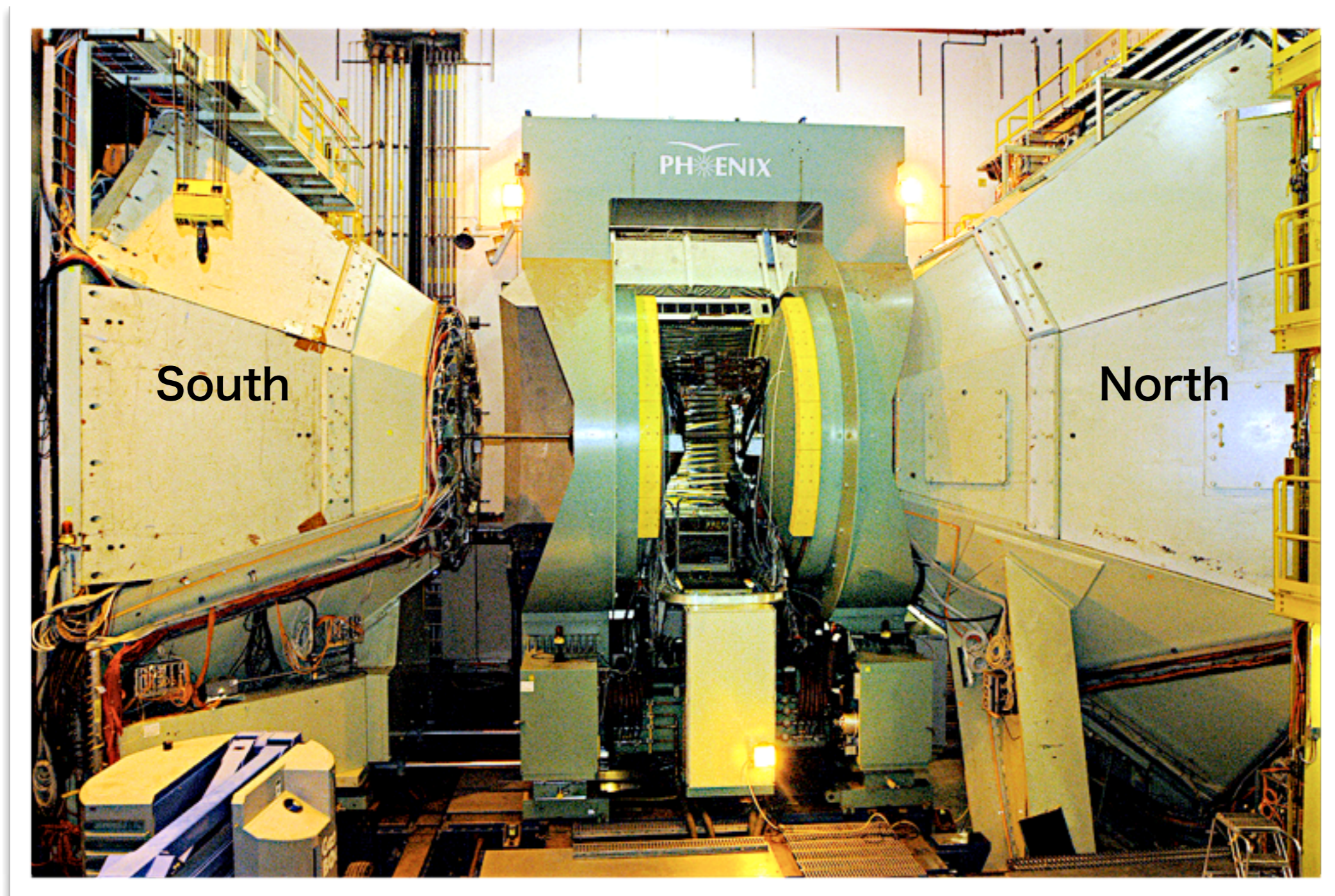
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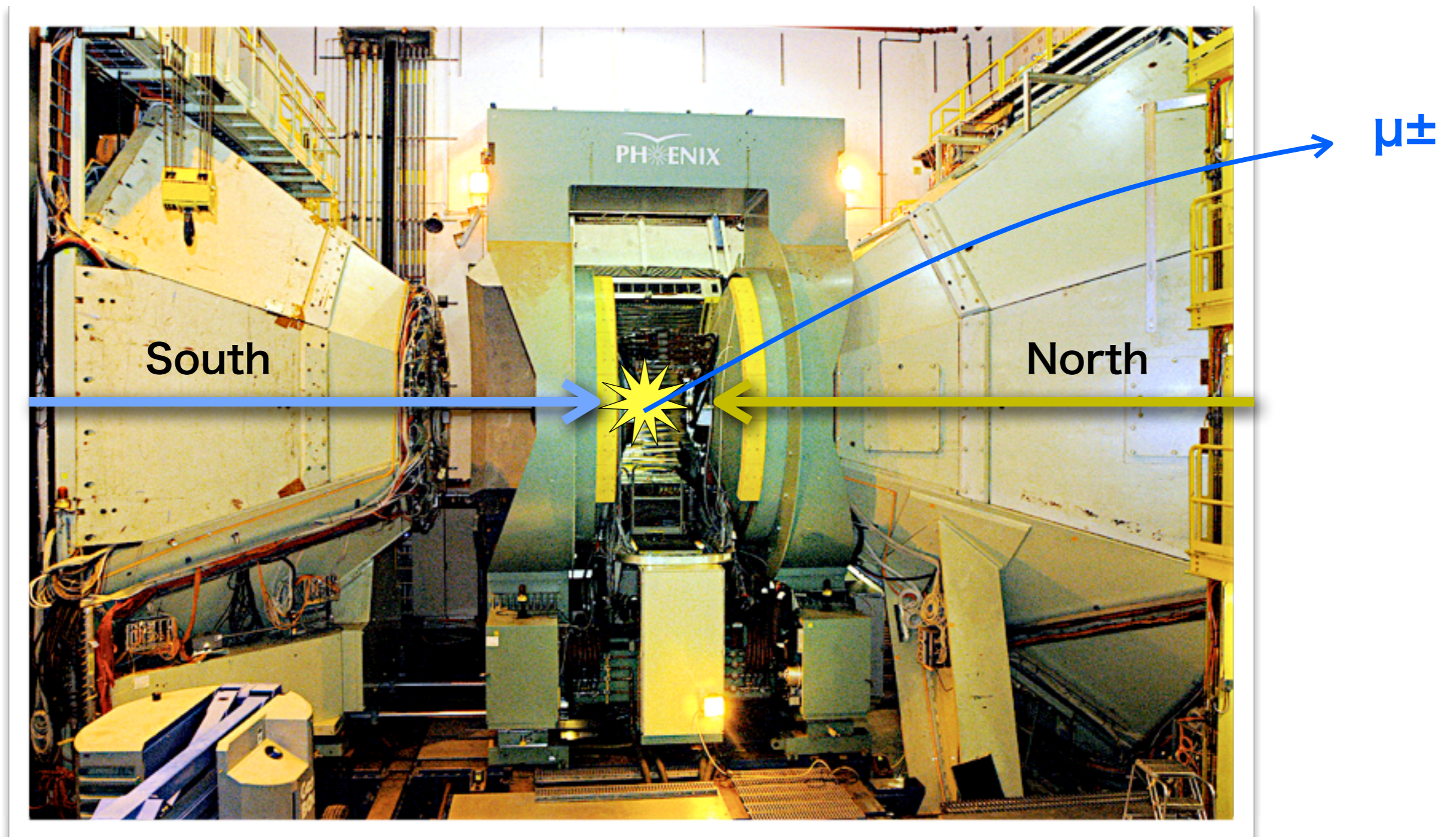
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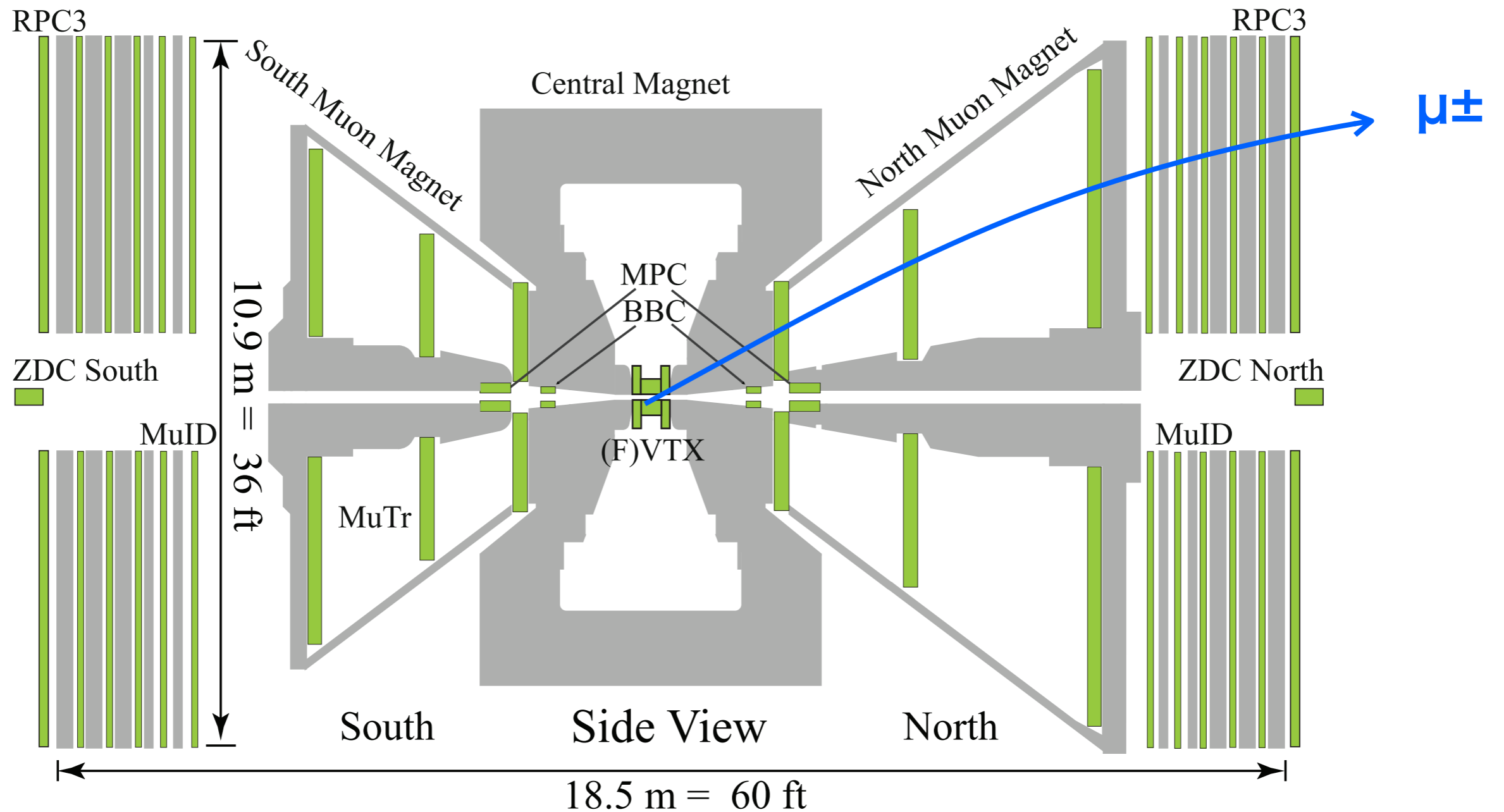
# PHENIX Muon Arms



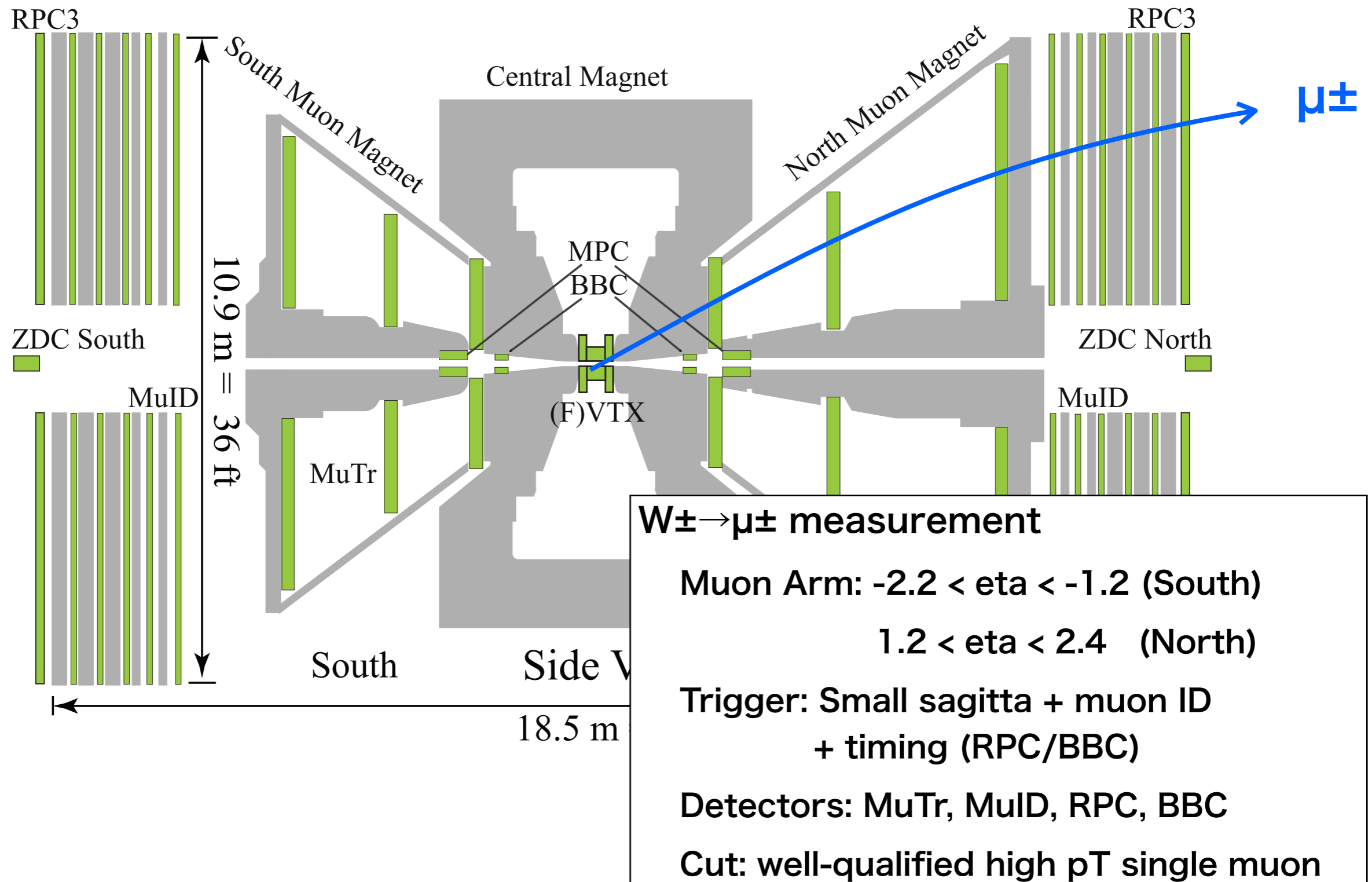
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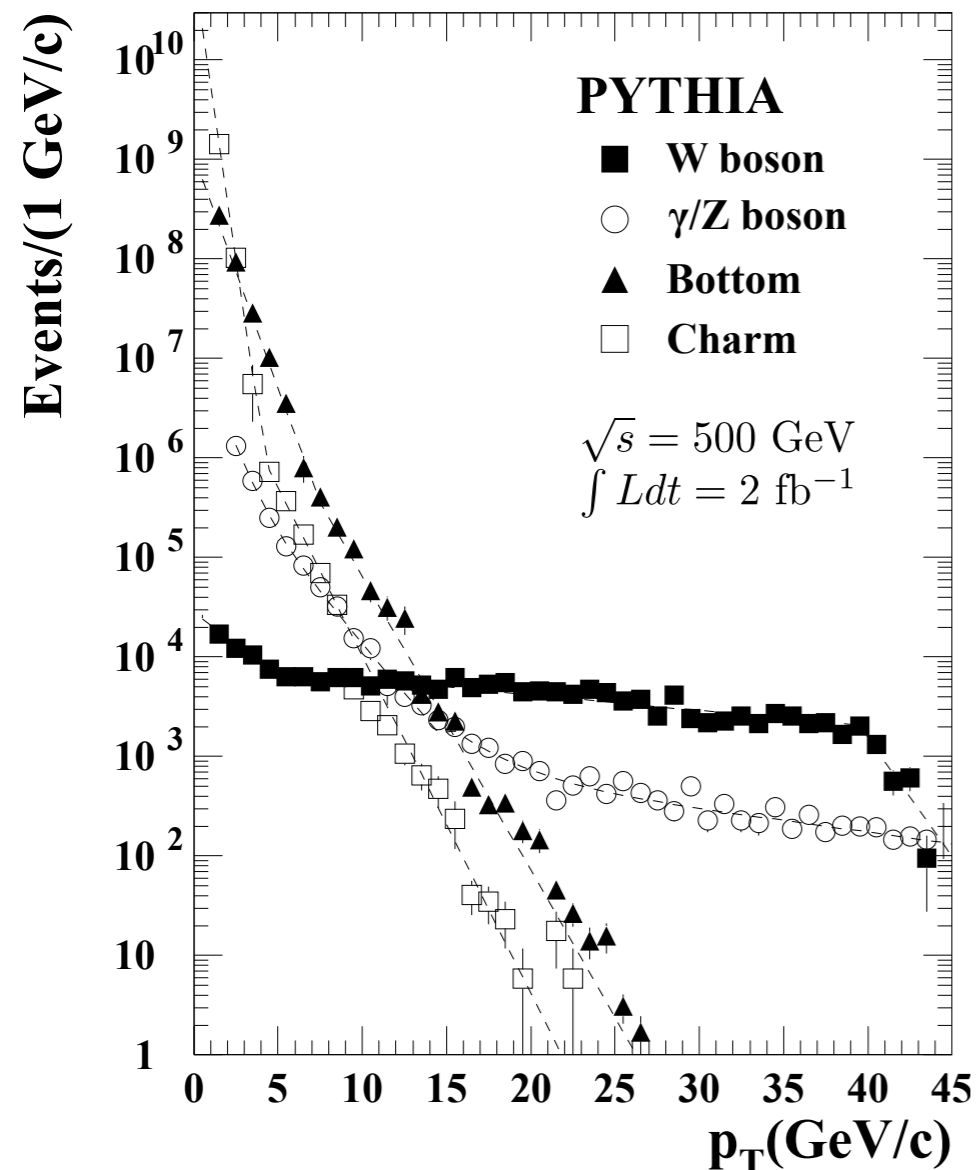


# PHENIX Muon Arms



# Muon Trigger System

- BBC trigger: “minimum-bias collision” + timing w/ Cerenkov counters
- MuID trigger: conventional, requires “deep” hit pattern for muons in MuID



BBC



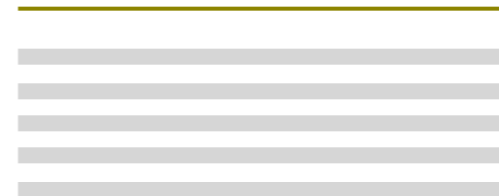
BBC



MuTr



MuID



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- Year 2011: MuTr only (“SG1”), Year 2012: MuTr + RPC3 (“SG1 x RPC3”)



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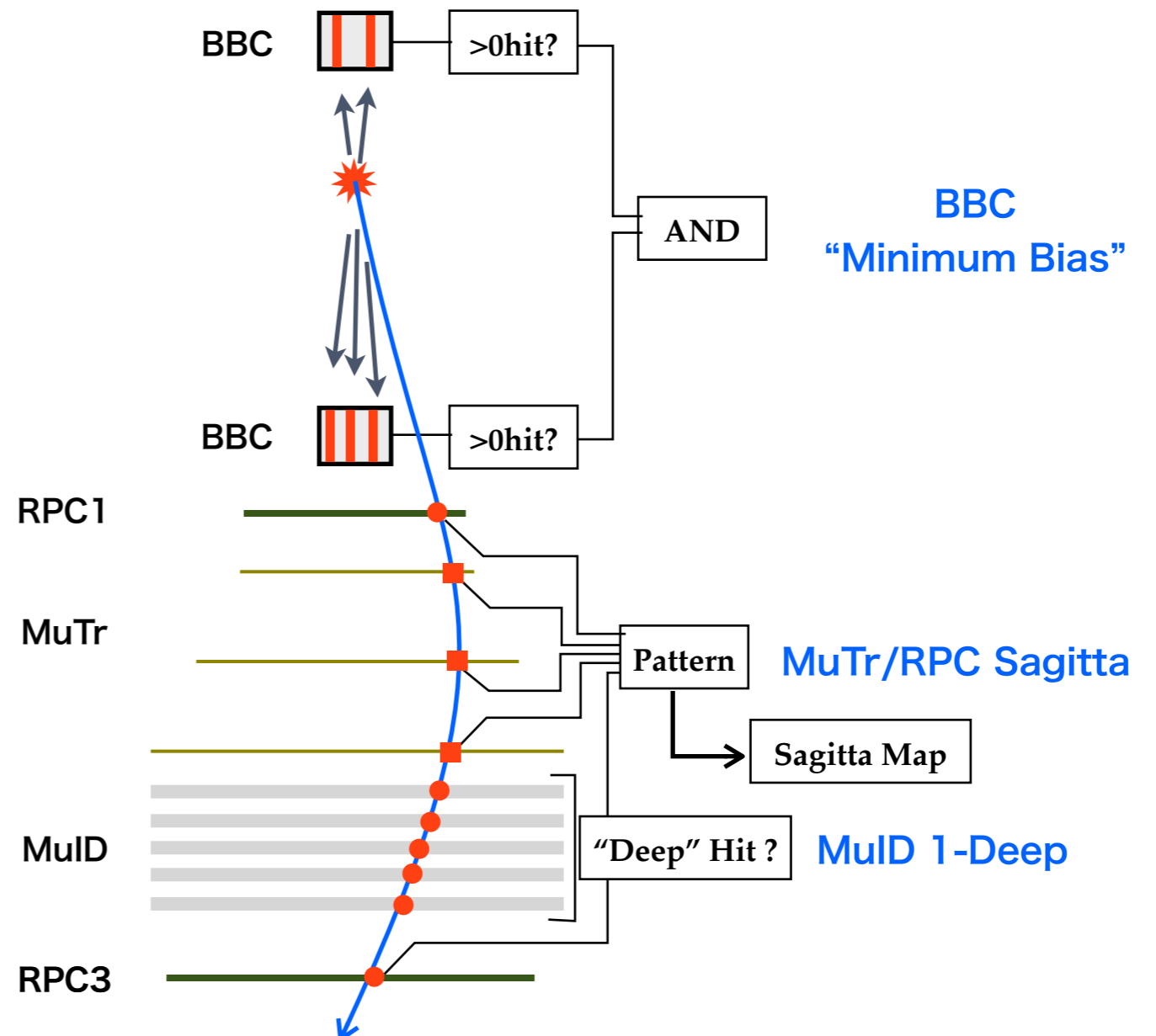
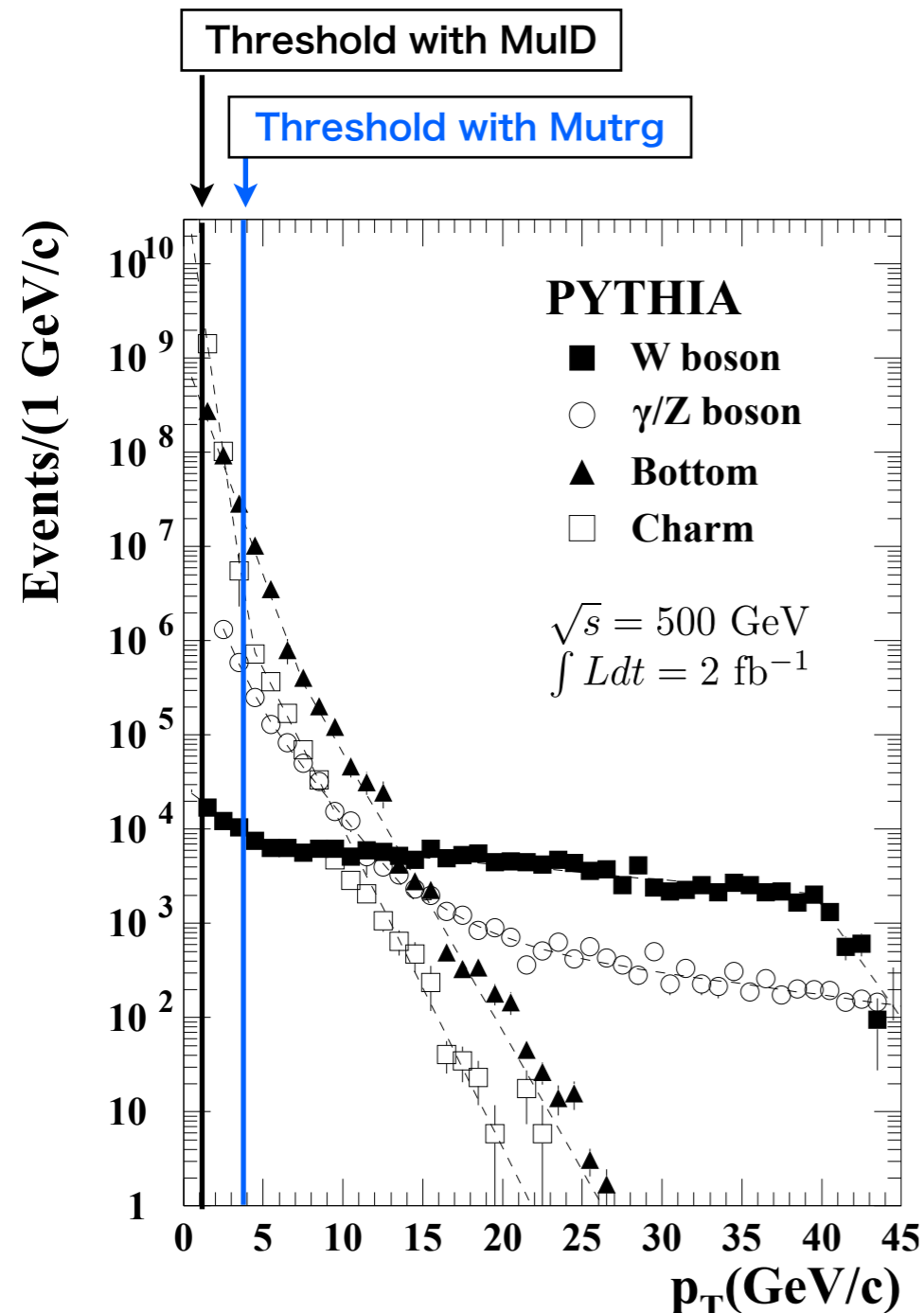
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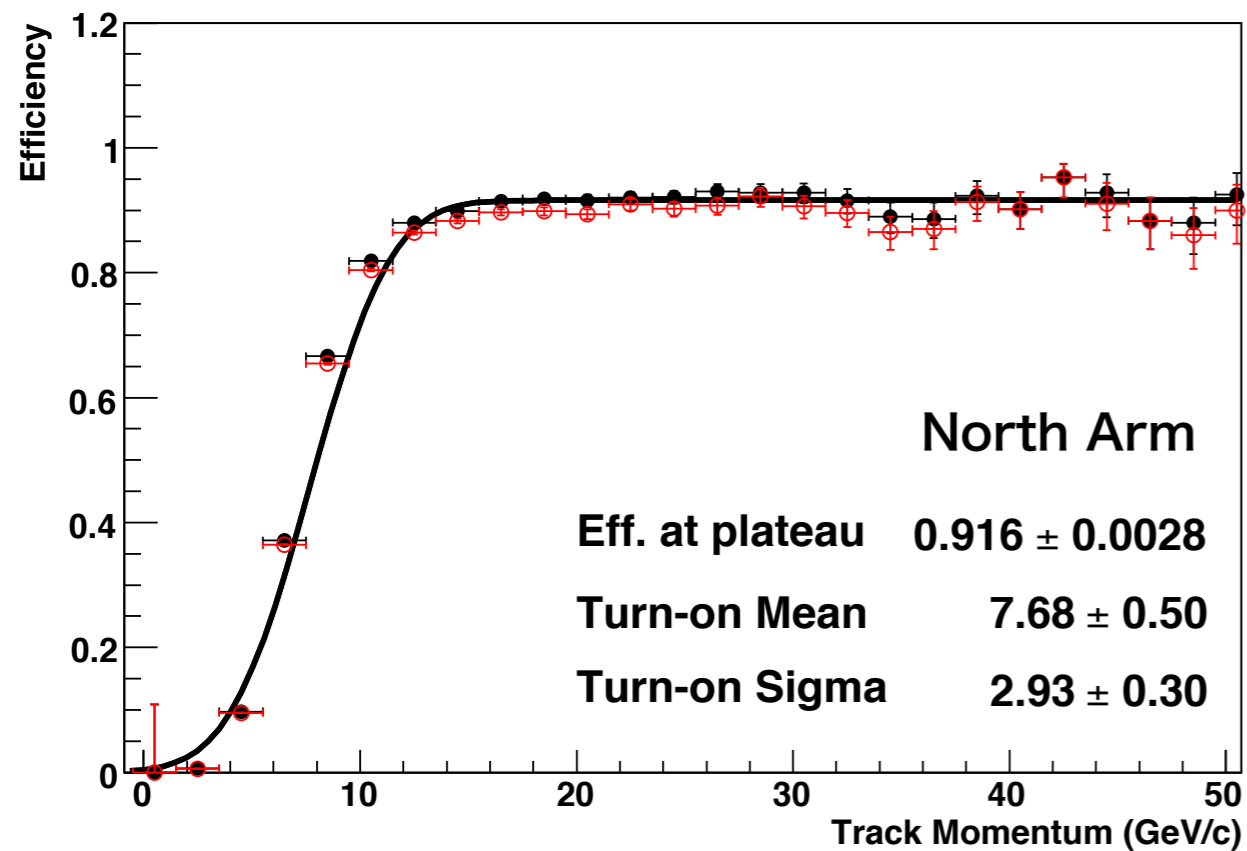


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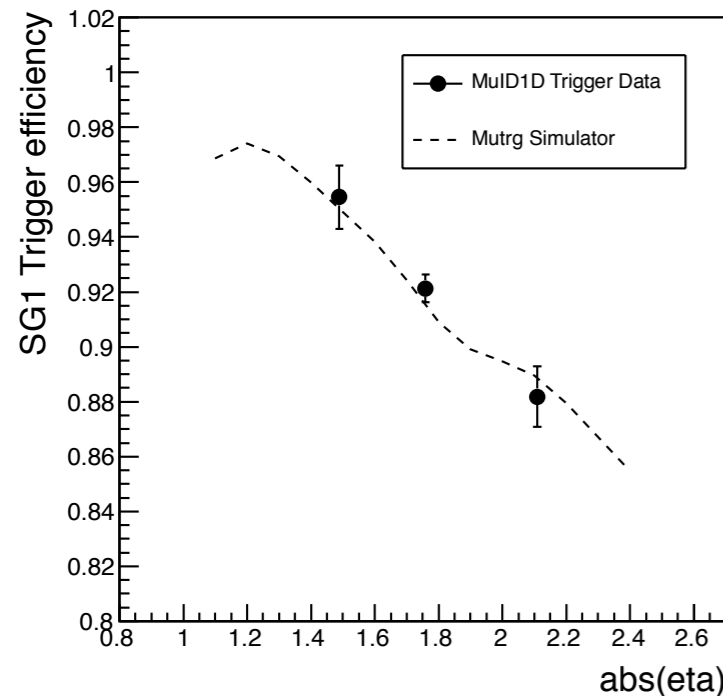


# Trigger performances (Mutrg)

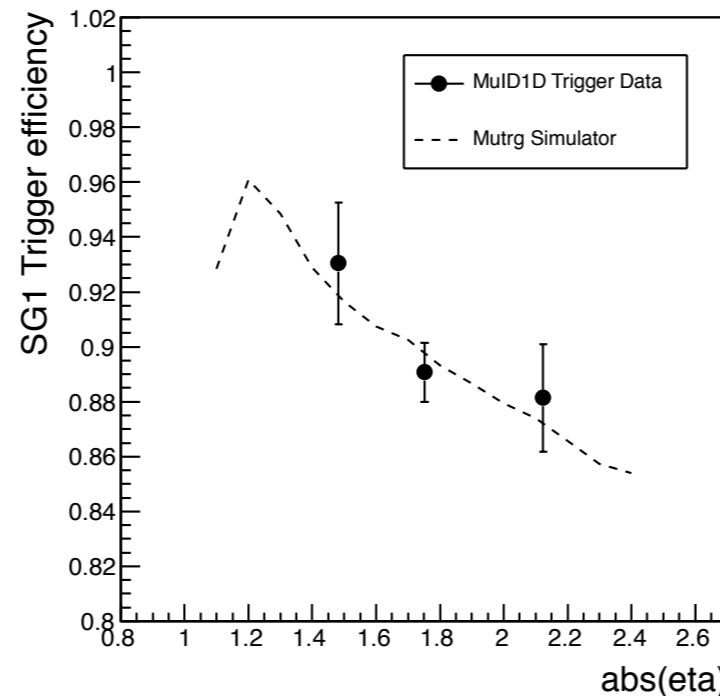


Turn-on curve

South Arm

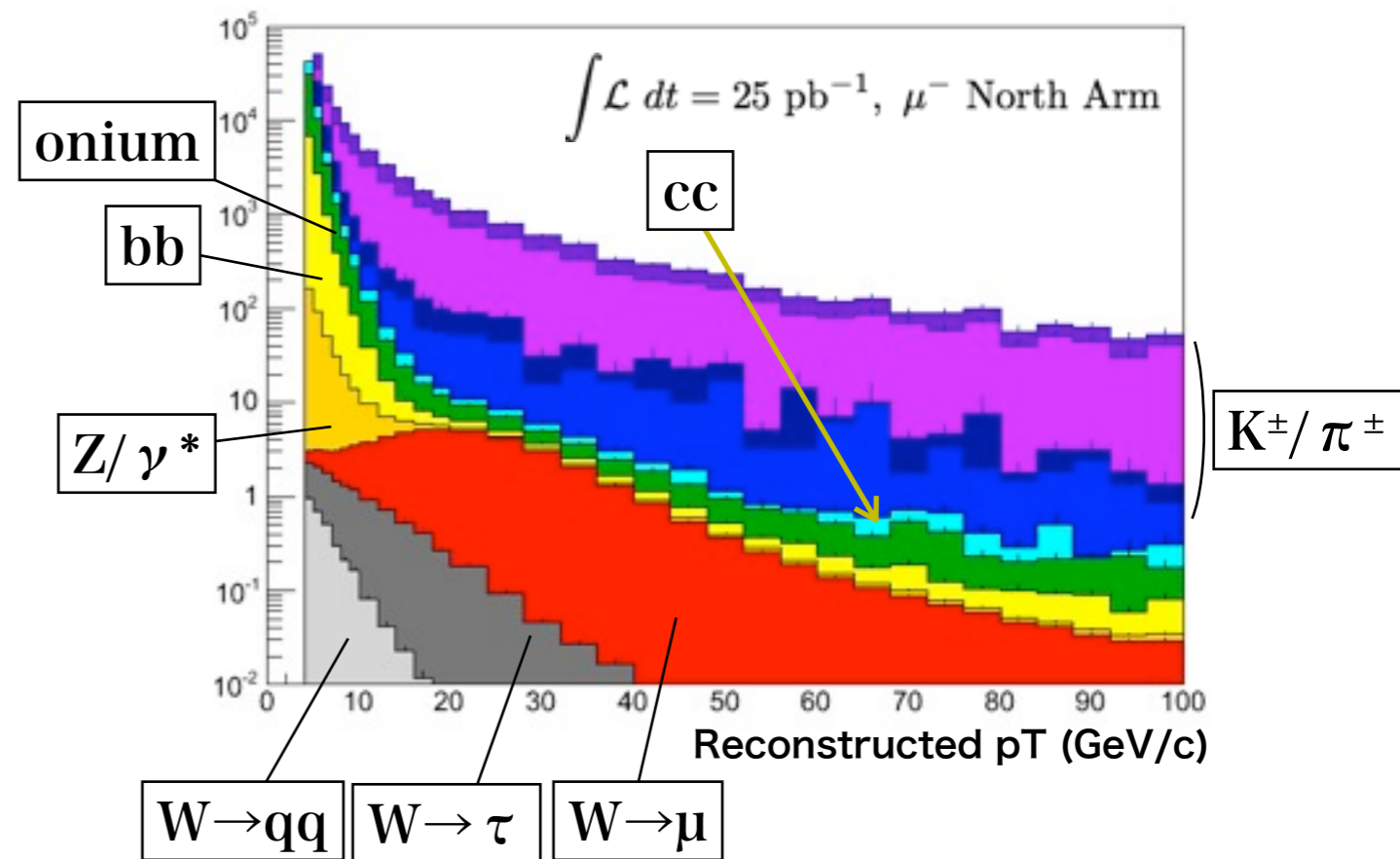
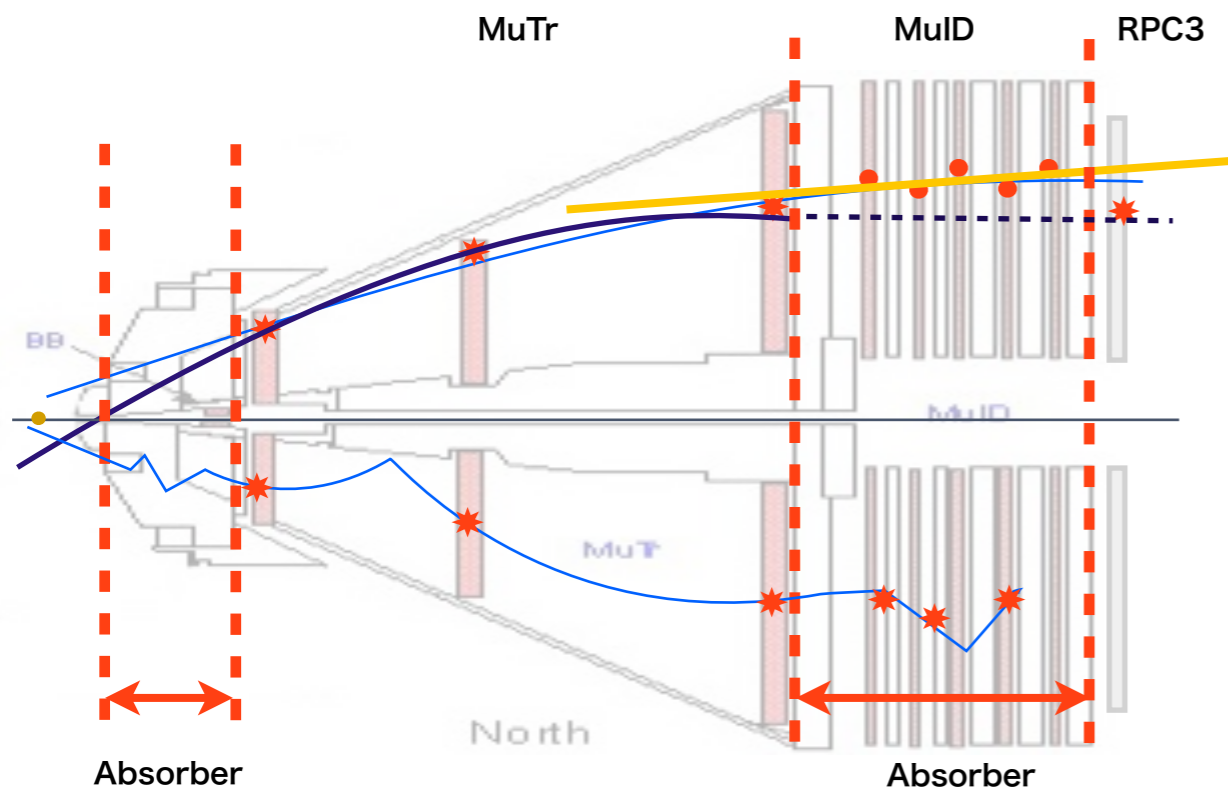


North Arm



Plateau efficiency

# Forward Muon Analysis



**Signal: high  $p_T$  single muon**

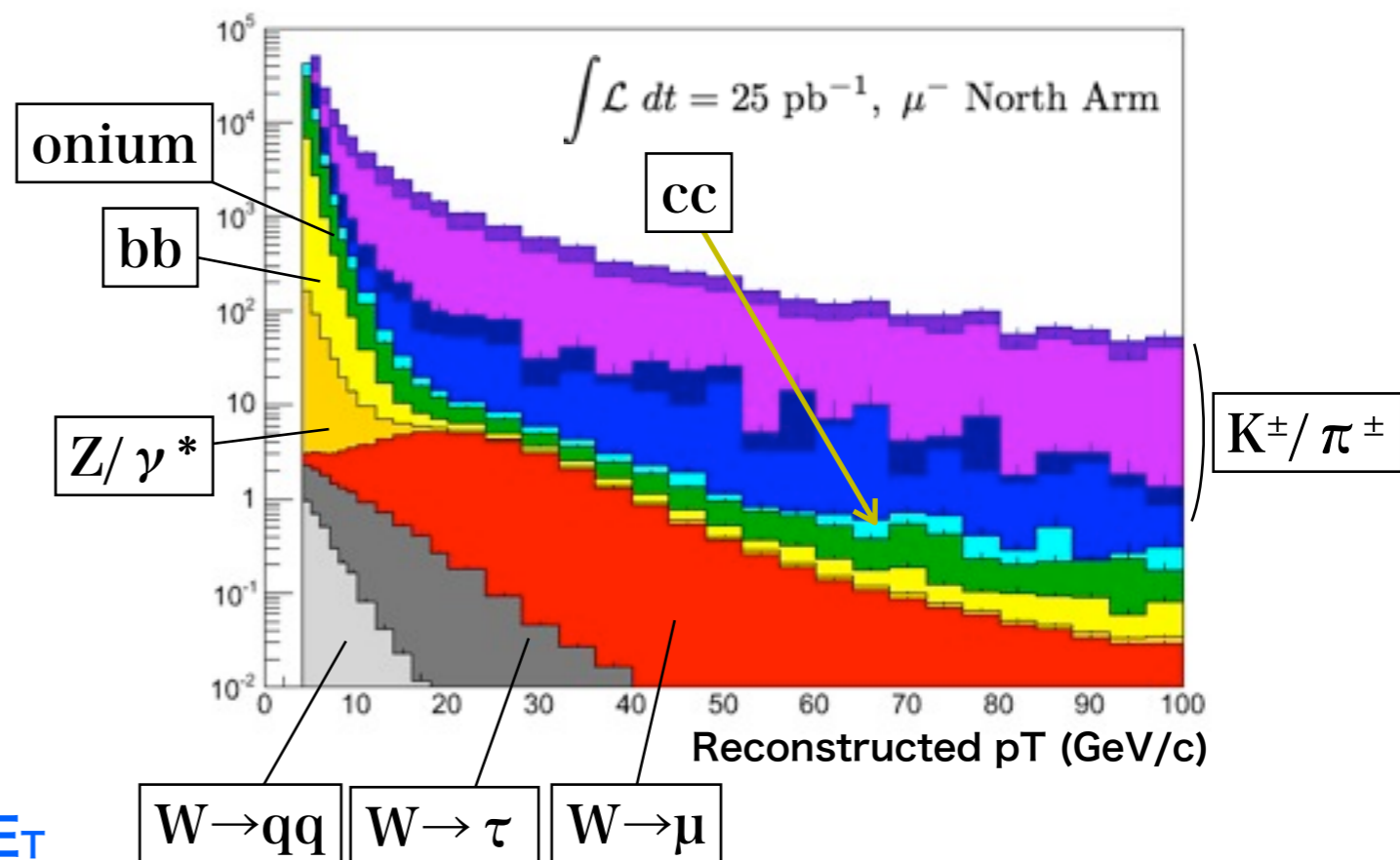
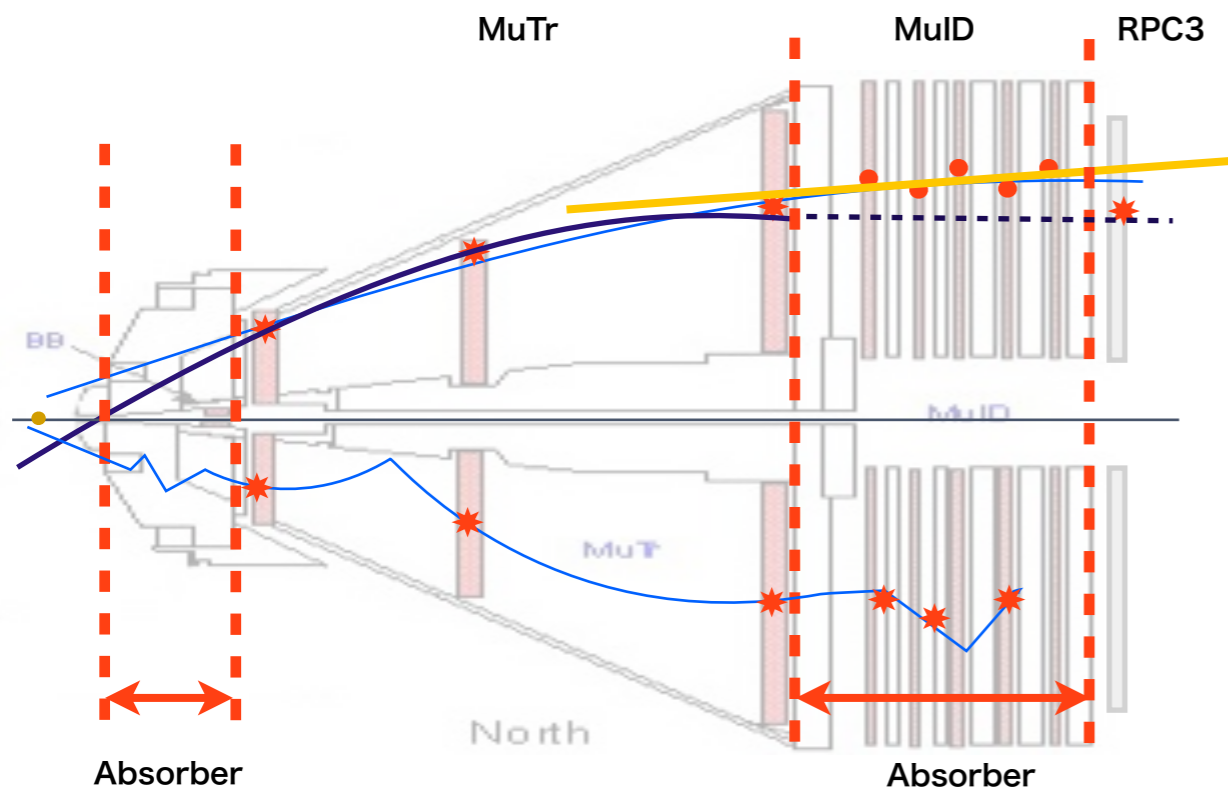
**Backgrounds:**

- Heavy flavor, onium (true muon, **irreducible**)
- “Fake high  $p_T$ ” caused by decayed hadrons

**Tight cuts are applied for “consistency of true high  $p_T$  muon”.**

- small multiple scattering : MuTr/MuID/RPC matching
- vertex requirement : Track/vertex(BBC) matching
- timing : RPC

# Forward Muon Analysis



Signal: high  $p_T$  single muon missing  $E_T$  isolation

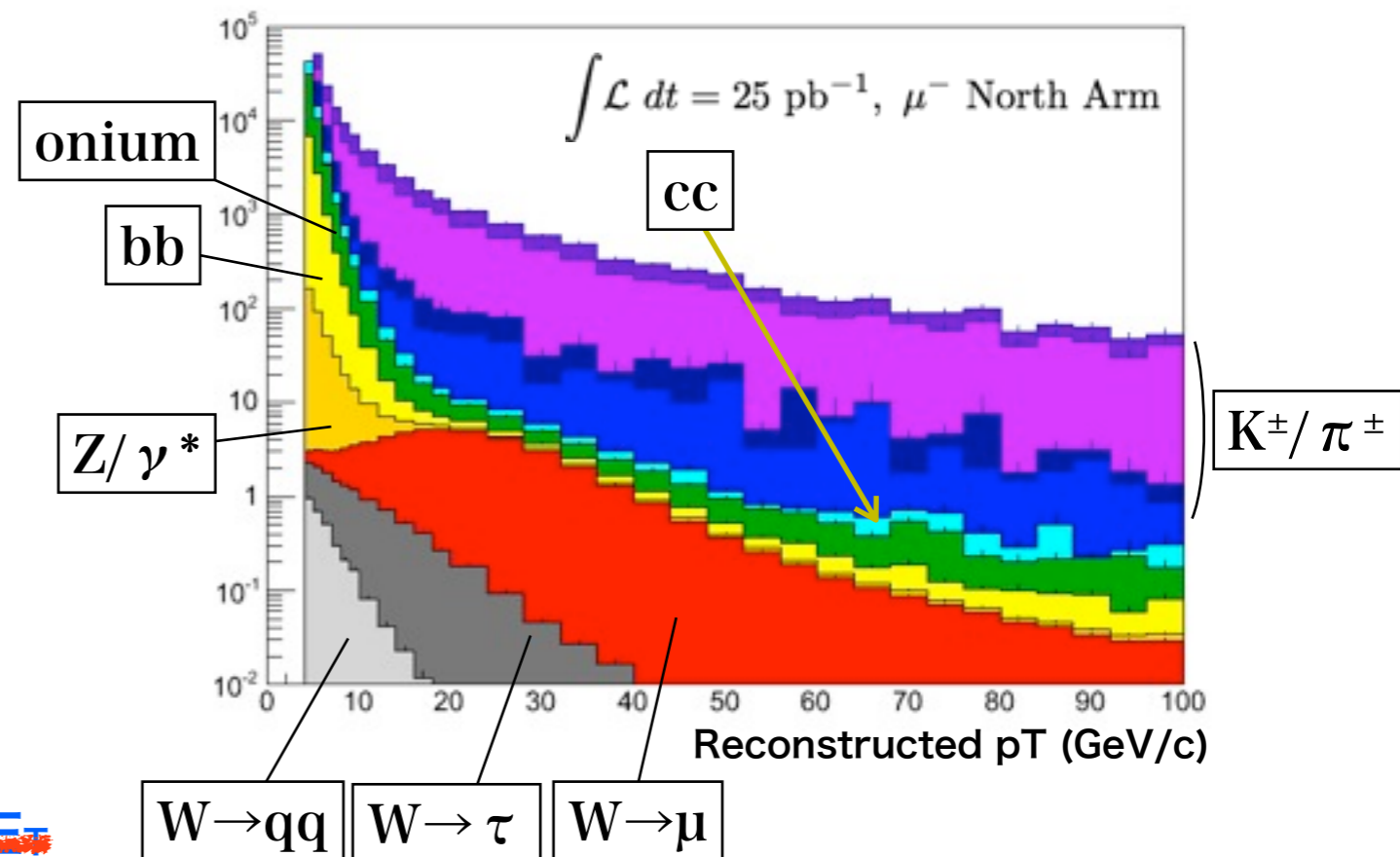
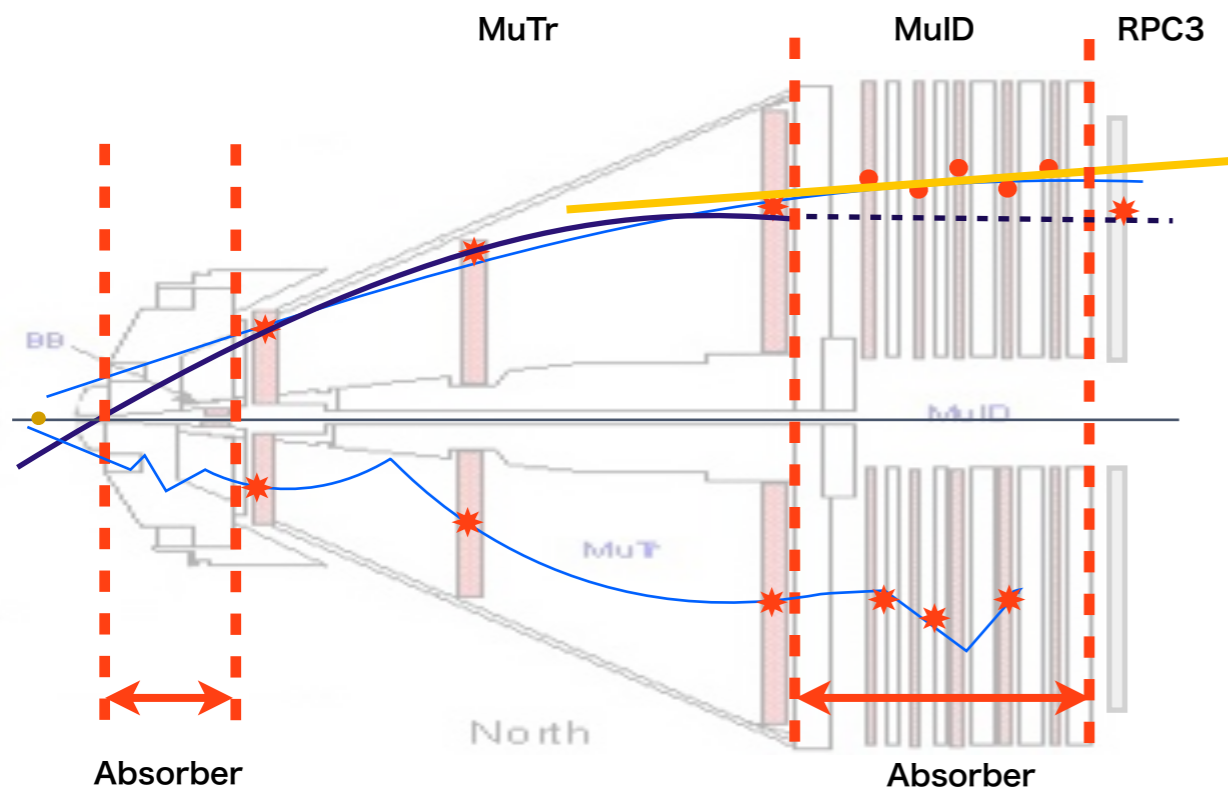
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~~missing  $E_T$~~   
~~isolation~~

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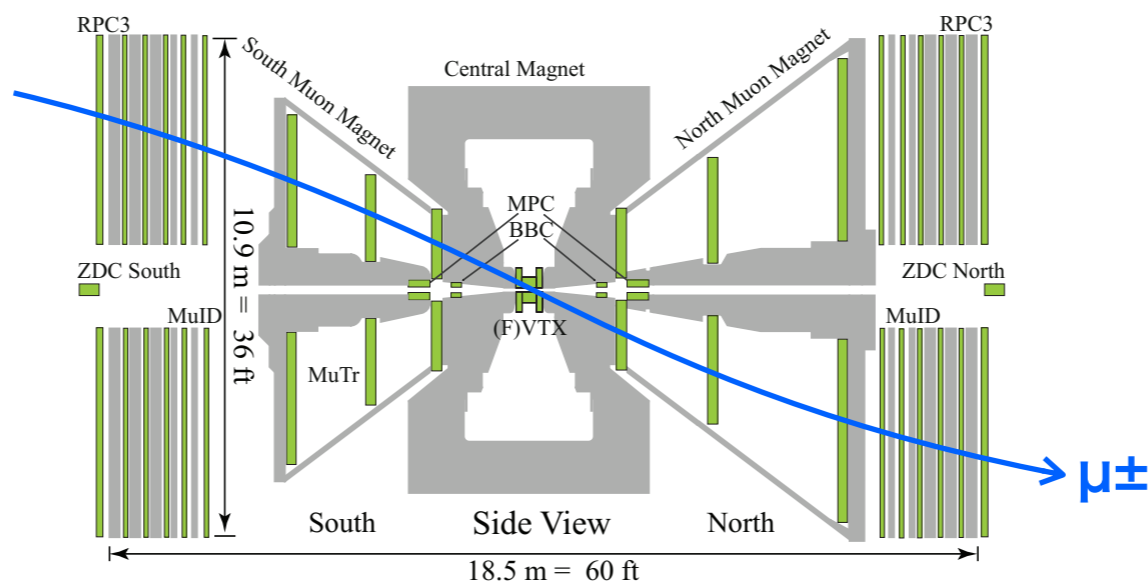
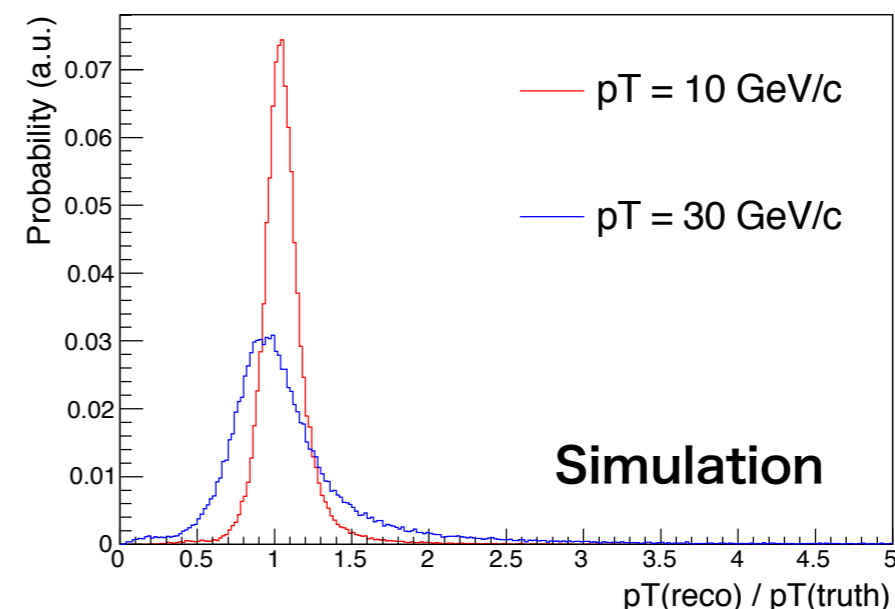
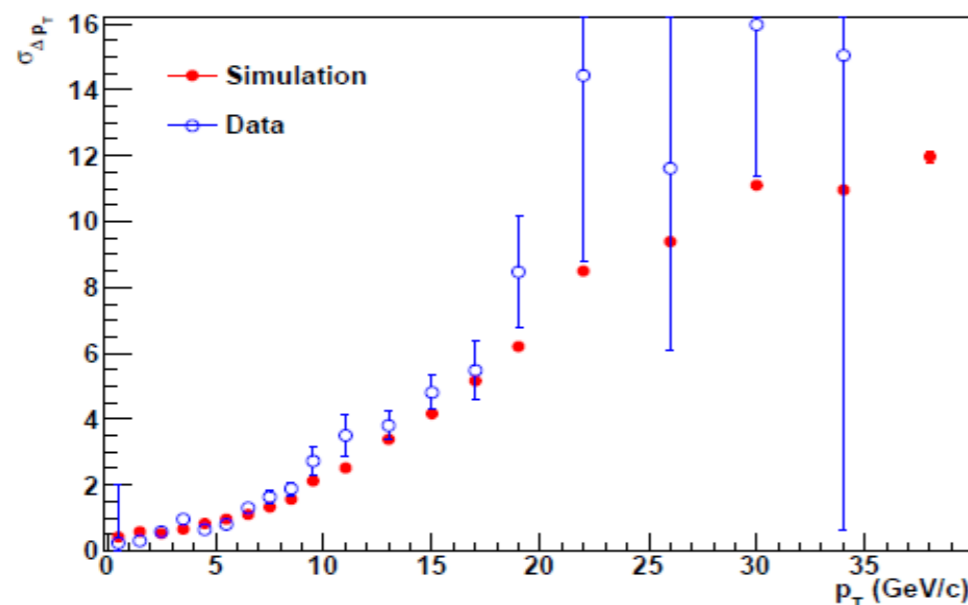
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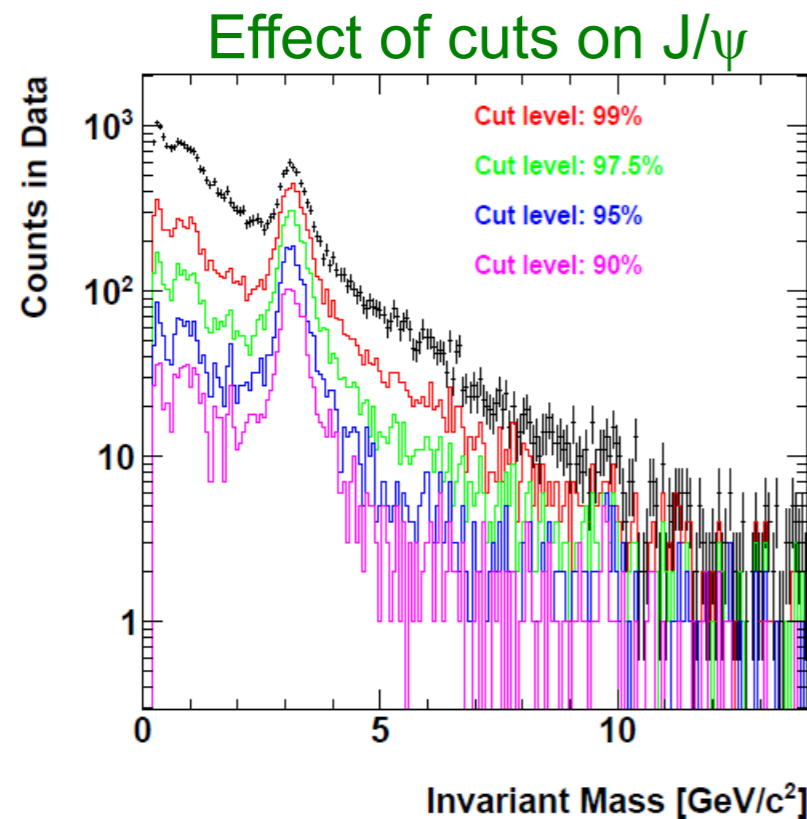
# Momentum resolution (smearing)

## Momentum resolution for cosmic muons



Confirmed the validity of smearing in the simulation with cosmic muons which punch through South&North Arms.

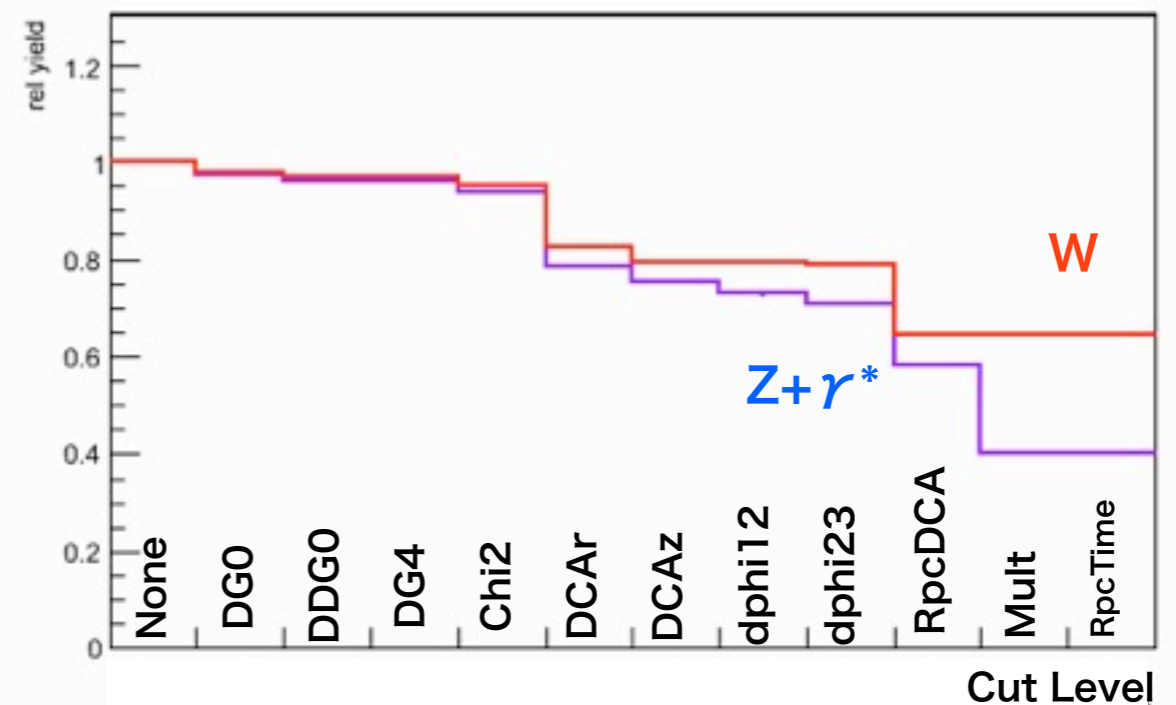
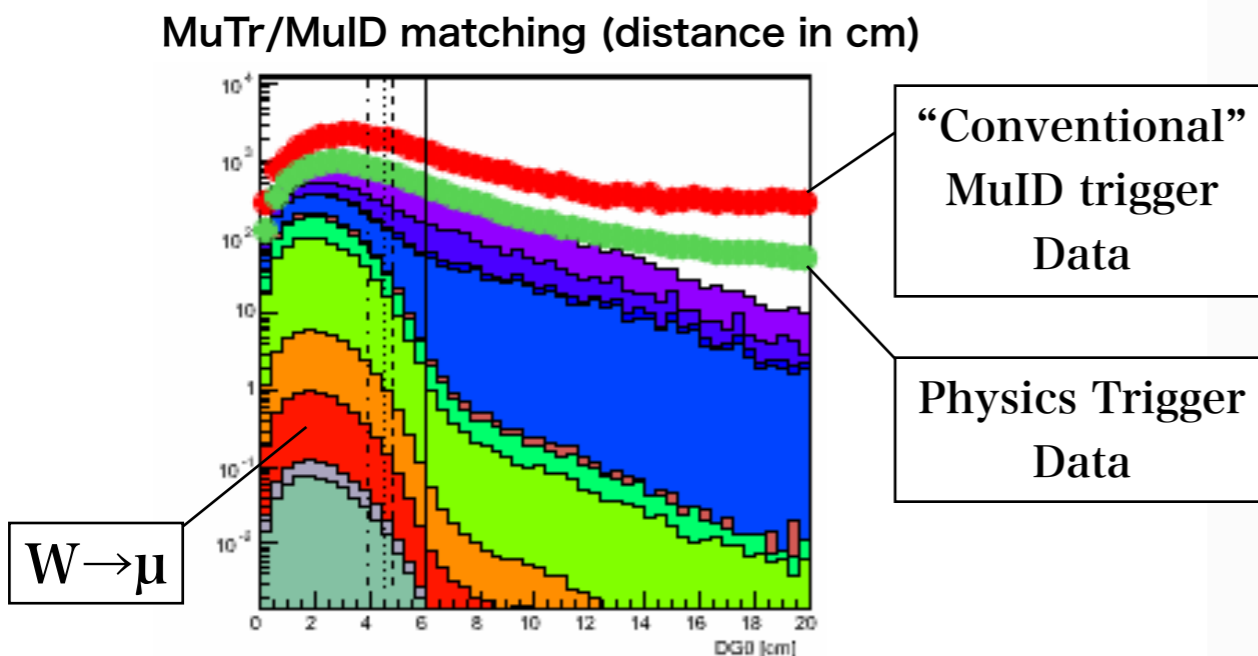
# Validation of Cut variables



- Validation of cut positions with  $J/\psi$

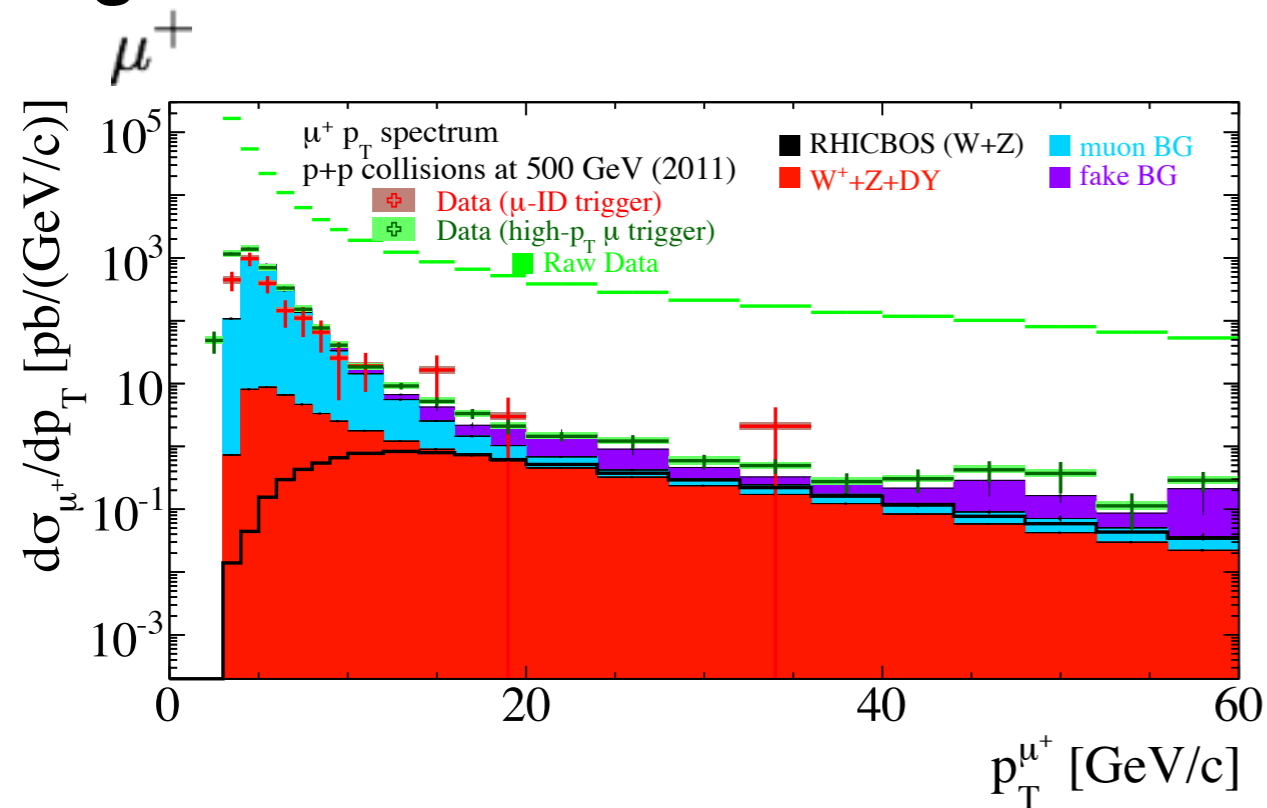
## Cuts in simulation

97.0 % distribution  $\mu^-$  at 10.00 GeV



# Single Muon Spectrum

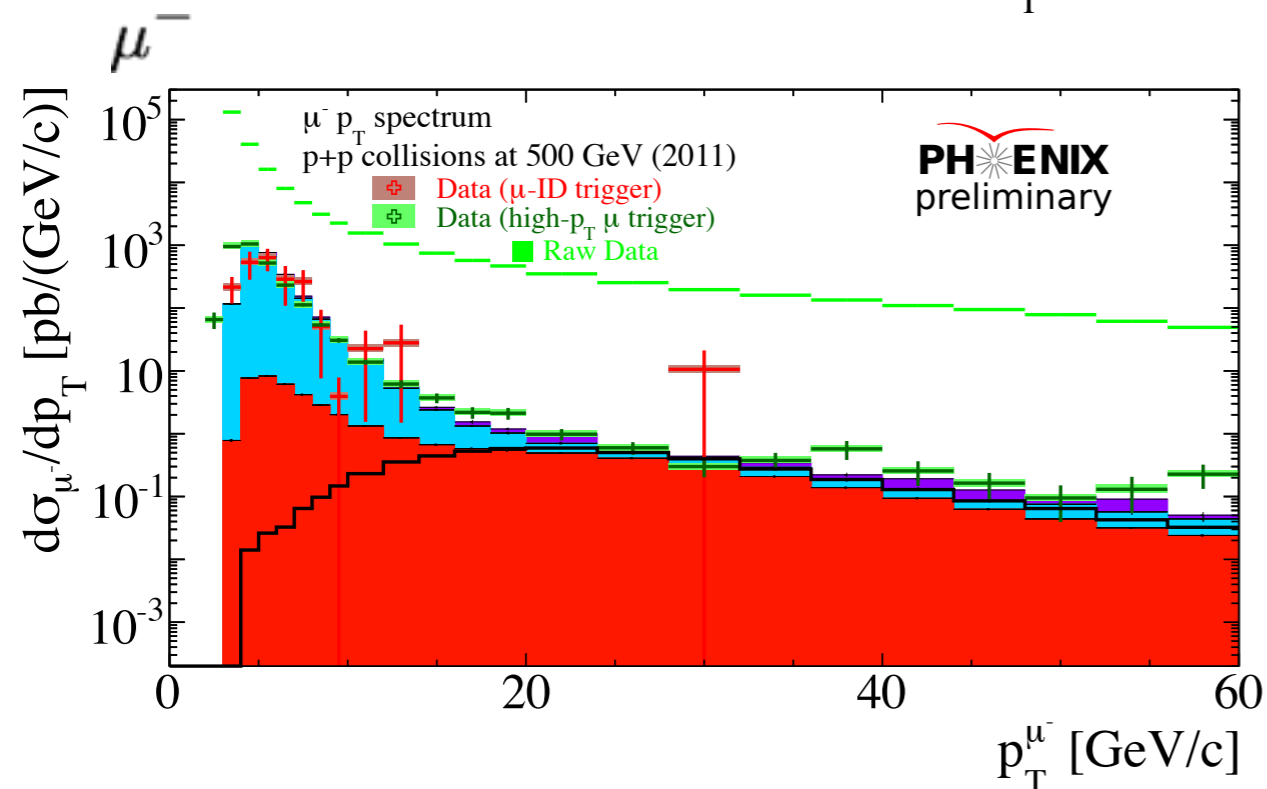
## Single muon candidates cross section at tightest cut level



### Corrections:

- “SG1xMulDxBBC” trigger efficiency correction
- Reconstruction x Acceptance correction
- RPC efficiency correction
- Luminosity correction

S/BG was extracted with assuming the W/Z cross section predicted by RHICBOS NLO calculation.



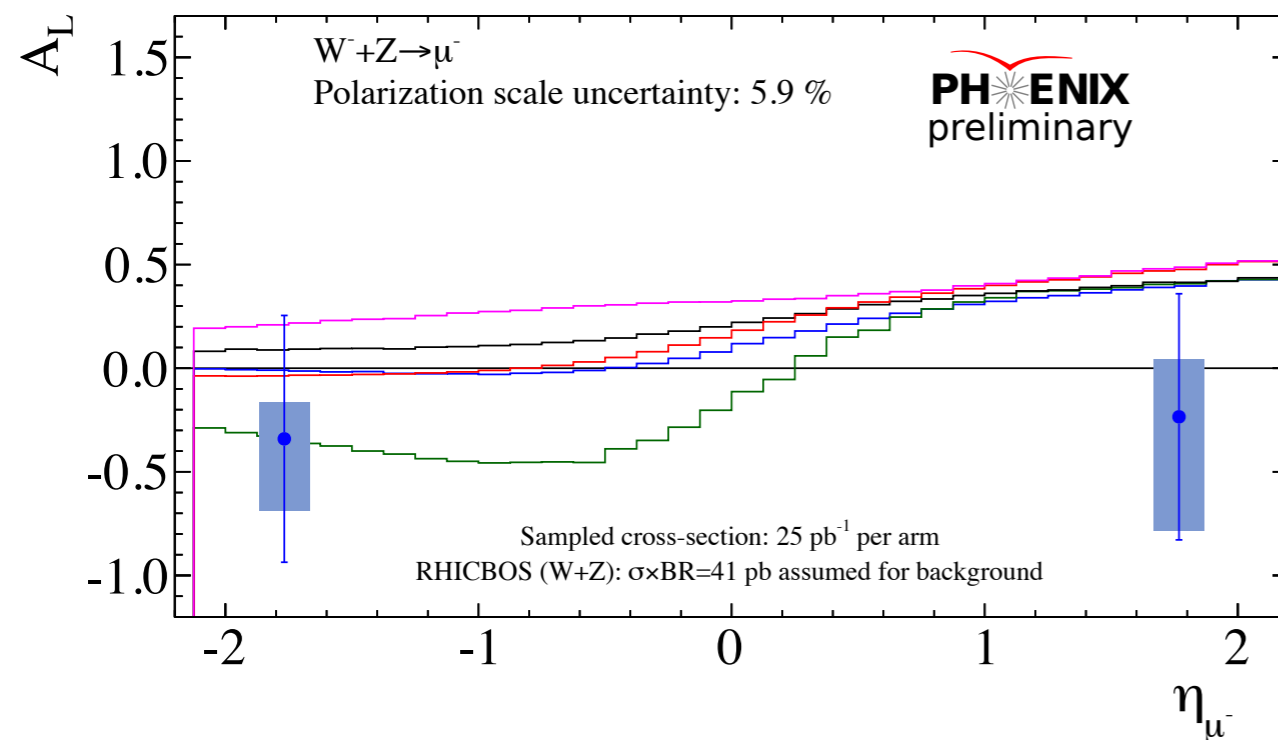
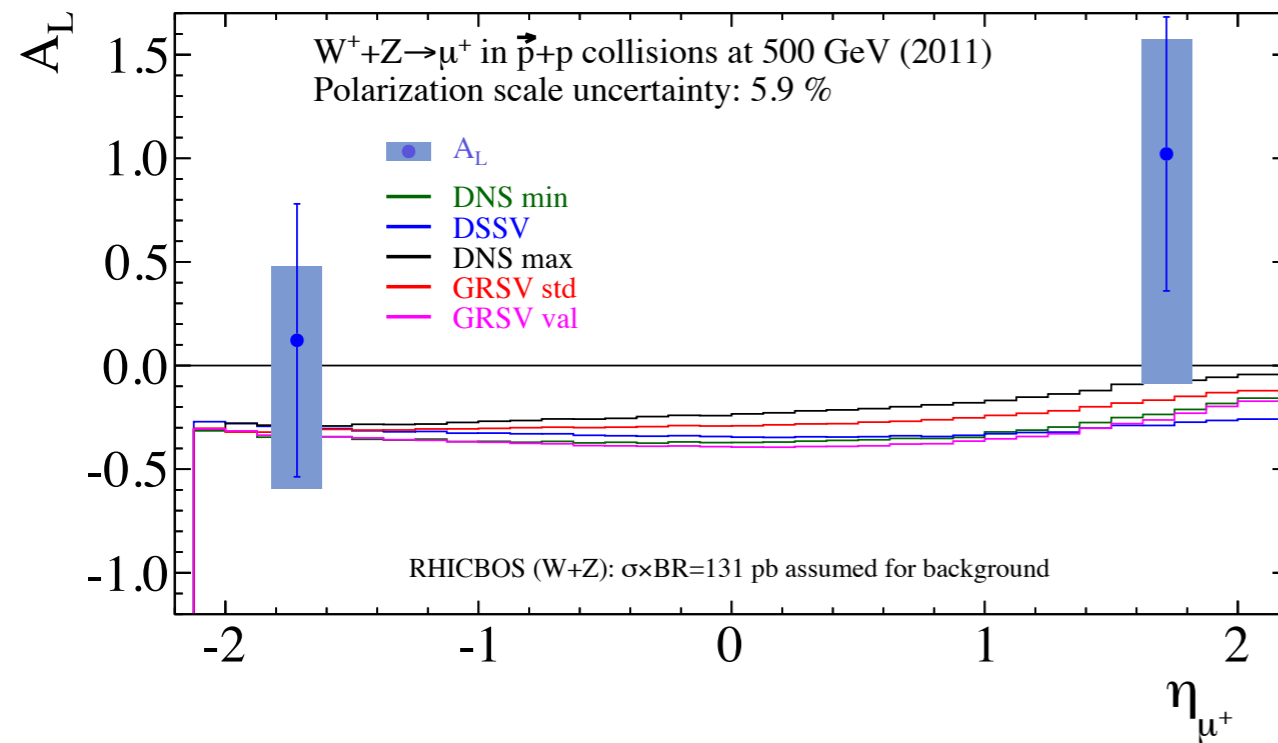
S/BG for muons in 18 - 60 GeV/c range with optimized statistical FOM:

S/BG	North	South
$\mu^+$	0.21	0.40
$\mu^-$	0.42	0.33

Factor [x0.5 - x2.0] range, as a conservative uncertainty of the S/BG

# First $W \rightarrow \mu$ single spin asymmetry (preliminary)

Preliminary approved in March 2012.



- $\sqrt{s} = 500$  GeV
- Luminosity:  $\sim 25 \text{ pb}^{-1}$
- Pol. :  $\sim 50\%$

First forward W asymmetry result

# Status quo, and near future

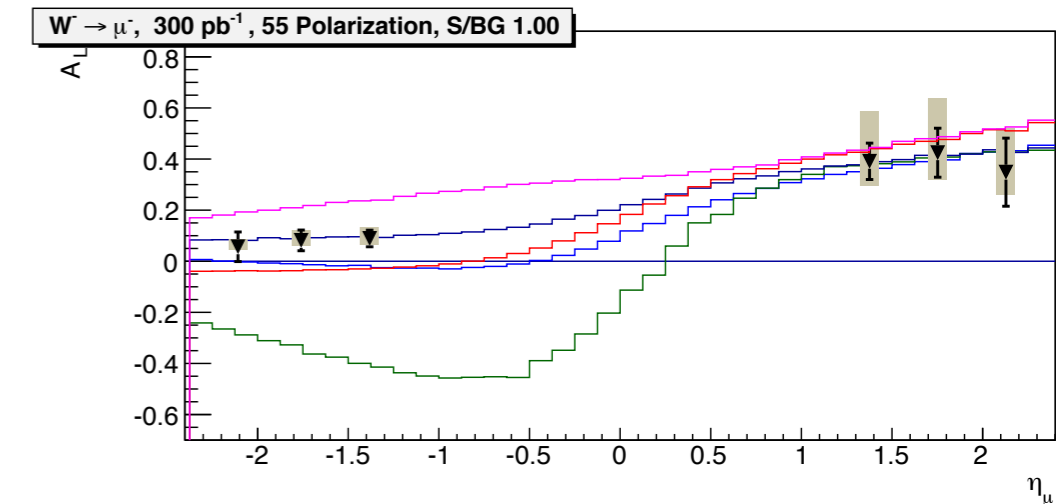
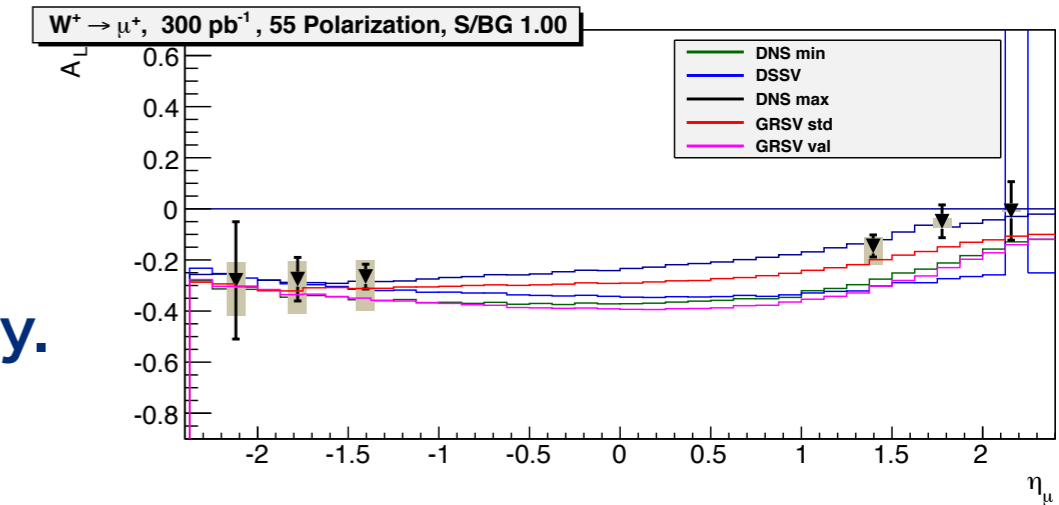
- Finalization of the analysis of the first  $W \rightarrow \mu$  data in 2011 is ongoing.
- Took about  $\sim 50 \text{ pb}^{-1}$  in 2012 with improved trigger with RPC.
  - Inclusion of VTX/FVTX detectors: better understanding / rejection of BG expected.
- Big data ( $\sim 250 \text{ pb}^{-1}$ ) will come up in 2013 with full detector ready.  
Now proposed for the beam use.

Year		2011	2012	2013
Luminosity ( $\text{pb}^{-1}$ )	$ \text{vtx}  < 30\text{cm}$	$\sim 16$	30	250?
	Full vtx	25	49	350?

# Summary

- The first preliminary result of forward arm  $W \rightarrow \mu$  single spin asymmetry
- In 2012 run  $\sqrt{s} = 510$  GeV run ended successfully.
  - Operation of new muon trigger with RPC3.
  - Taking data with VTX, FVTX, and RPC1.
- In 2013, an integrated luminosity of  $250 \text{ pb}^{-1}$  in  $|\text{vtx}| < 30$  cm is anticipated with full upgraded hardware set ready.

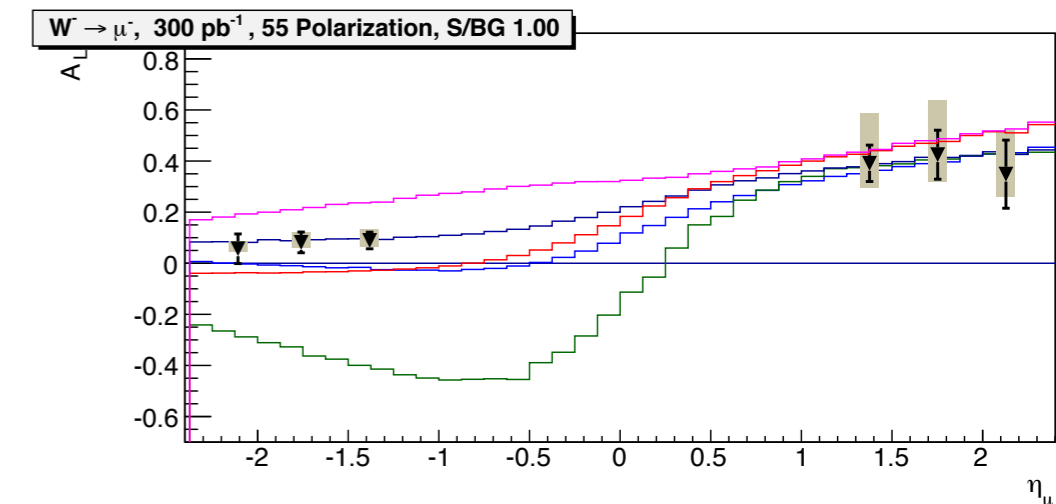
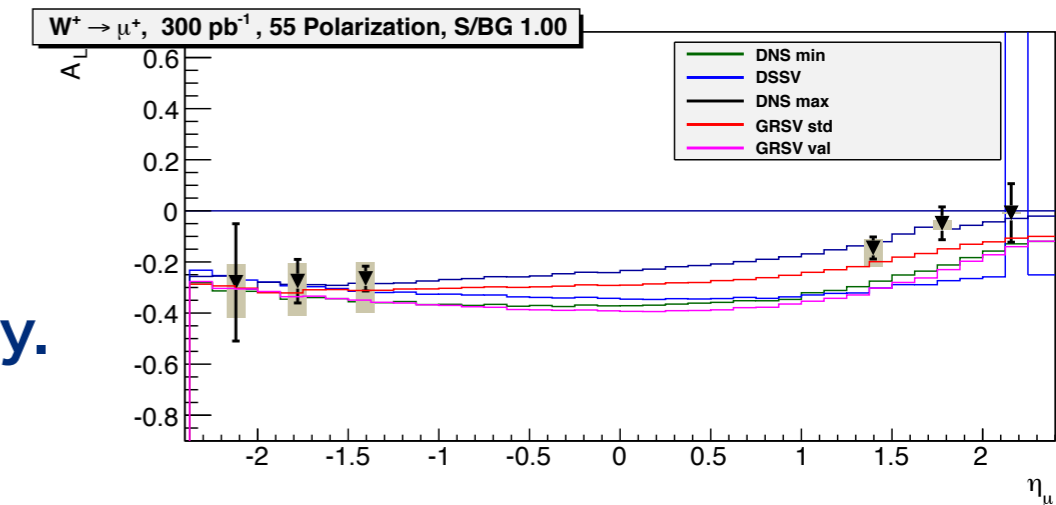
Expected single spin asymmetry in  $W \rightarrow \mu$  at  $300 \text{ pb}^{-1}$



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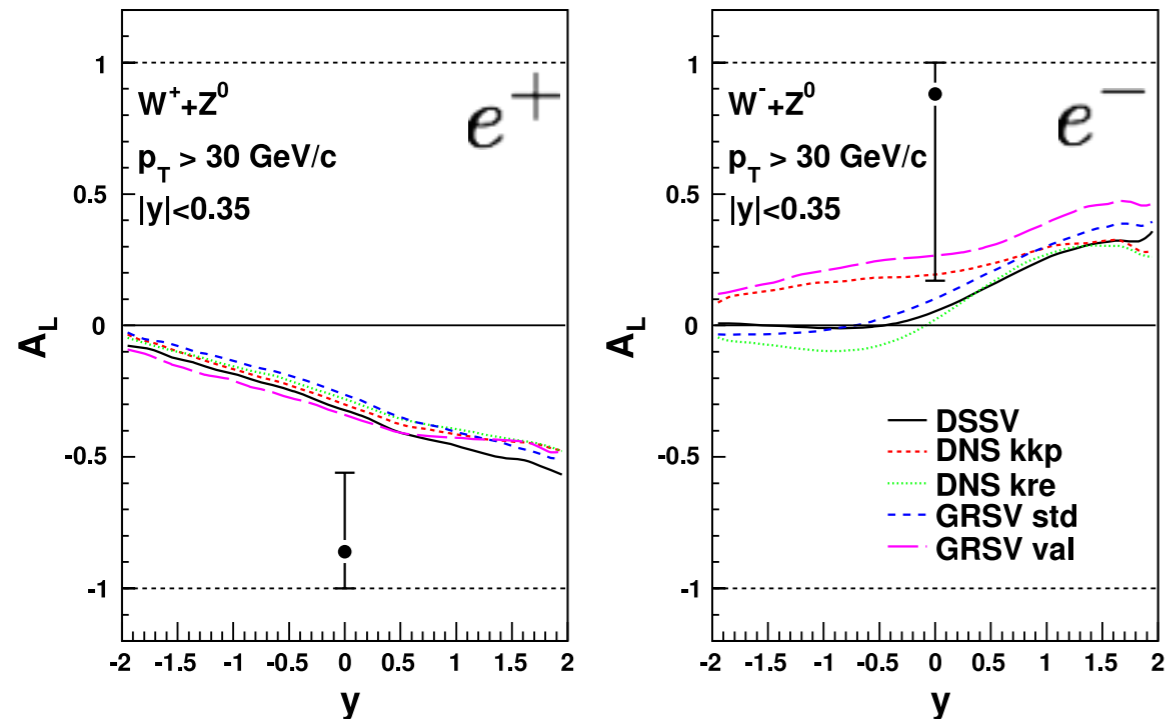
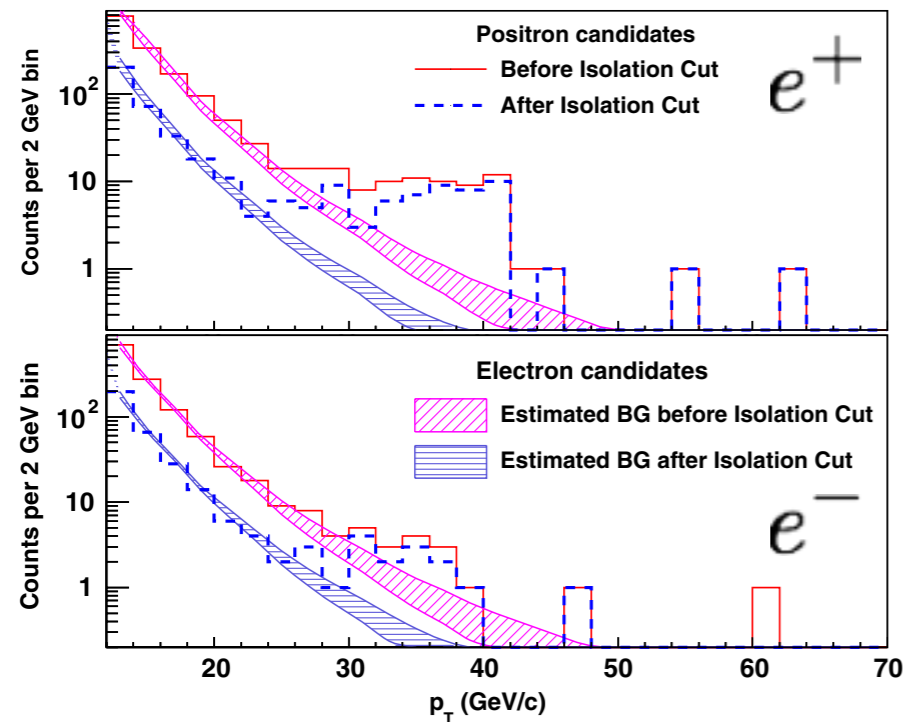
*Enacudo!*

# Backup

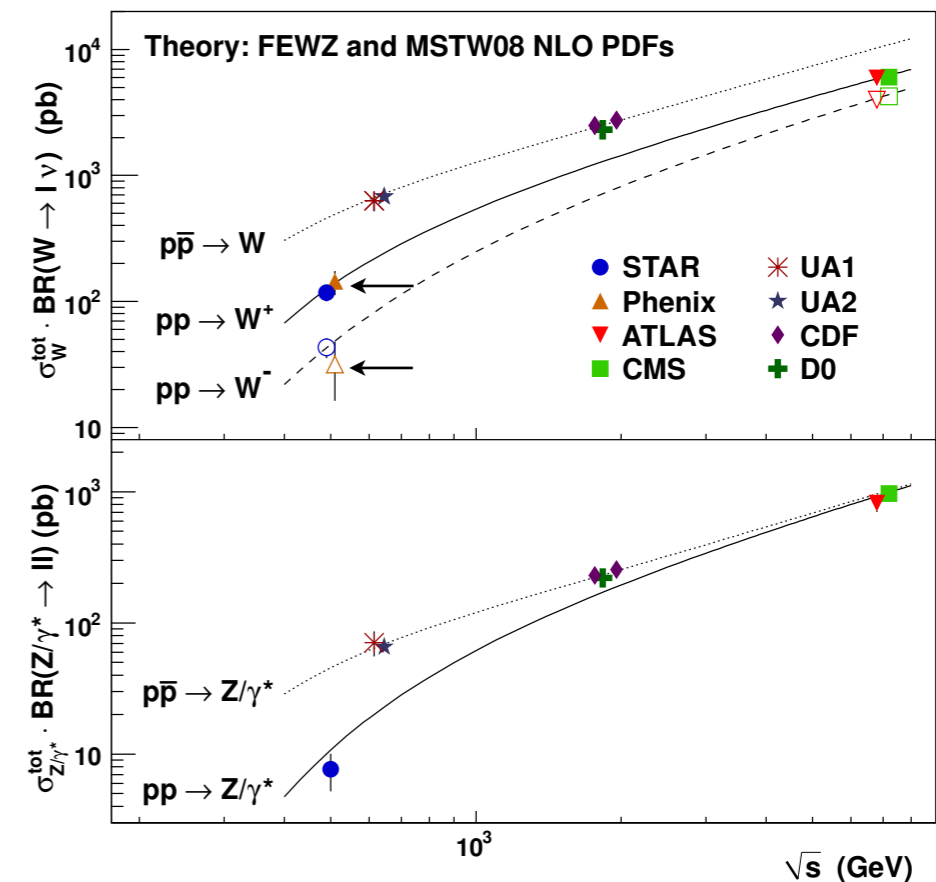
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# Run9 $W \rightarrow e$ Result in Central Arm

Run9  $\sqrt{s} = 500$  GeV integrated luminosity:  $8.6 \text{ pb}^{-1}$  in  $|\text{vtxz}| < 30$  cm (ERT 4x4b trigger)



PHENIX Collaboration PRL106.062001

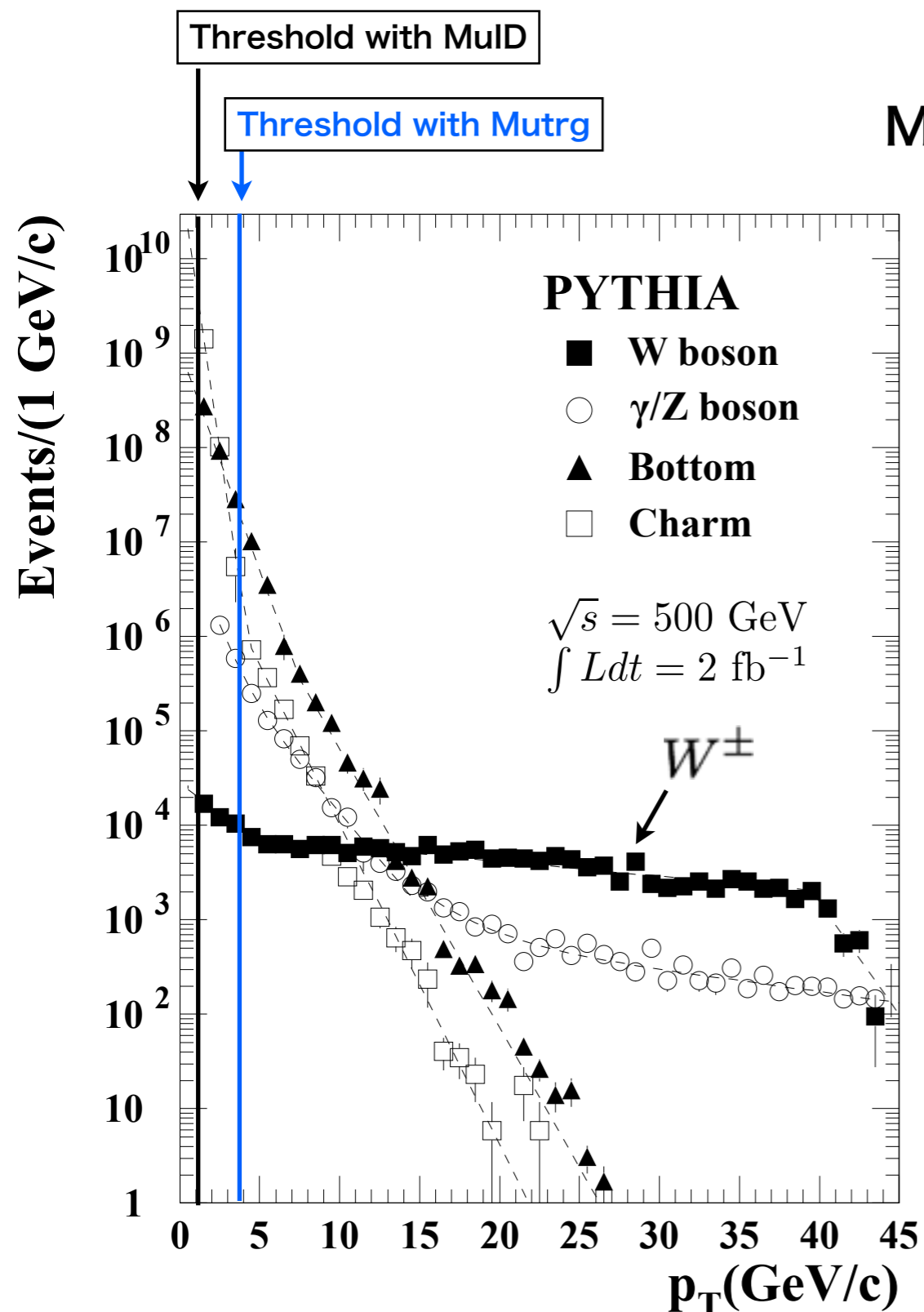


STAR Collaboration [arXiv:1112.2980v1](https://arxiv.org/abs/1112.2980v1)

Single Spin Asymmetry Result ( $p_T > 30 \text{ GeV/c}$ )

$$\begin{aligned}
 W^+ + Z^0 &: -0.86 \quad [-1, -0.56] \\
 W^- + Z^0 &: +0.88 \quad [+0.17, +1] \\
 ([ ] &: 68\% \text{C.L.})
 \end{aligned}$$

# Forward Muon Trigger Upgrade



## Motivation of PHENIX forward upgrade project:

Due to limited trigger bandwidth, the original muon trigger “MuID” is short to acquire all W collisions without pre-scaling.  
==> Needs a **high momentum trigger**.

### [ Strategy ]

1. Discriminates muon momentum using **sagitta**  
(Mutrg: parasitic trigger electronics inside MuTr + RPC)  
==> Trigger  **$p_T > 4 \text{ GeV/c}$**
2. For ID of spin pattern / bunch crossing at high collision rate, beam beam counter (BBC) is not tolerable.  
==> Introduce resistive plate chambers (**RPC**)
3. Introduce additional hadron absorbers to reject hadronic backgrounds.
4. FVTX detector will work for increasing analysis power.

# PHENIX Forward Upgrade Program

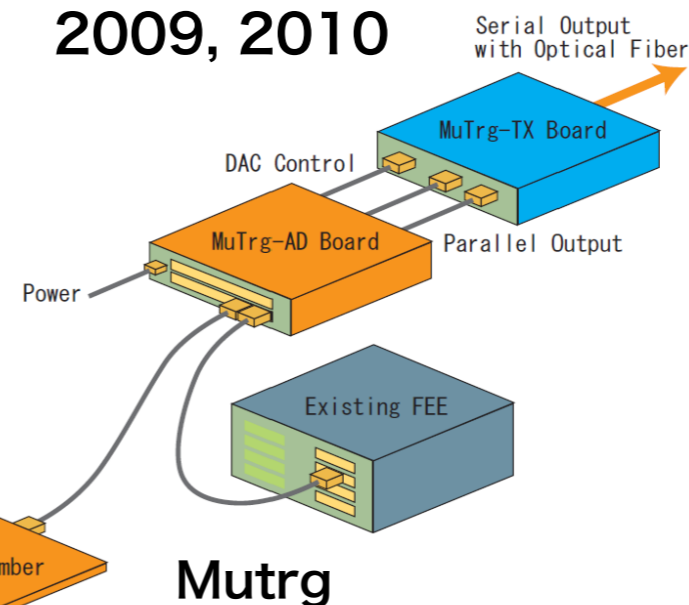


Absorber

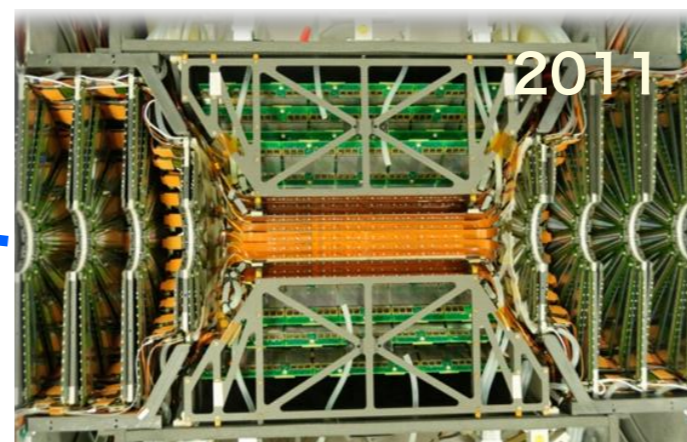
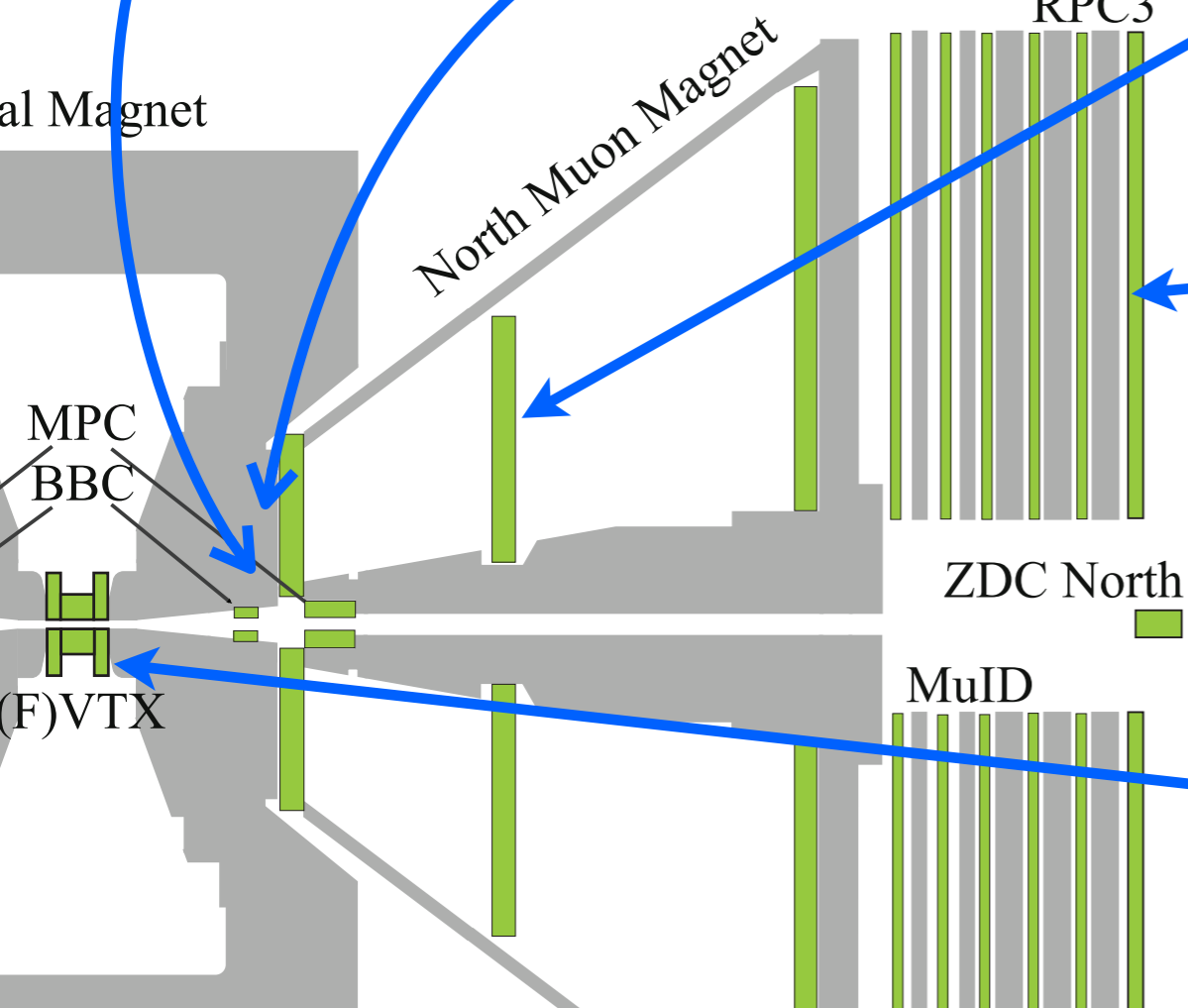
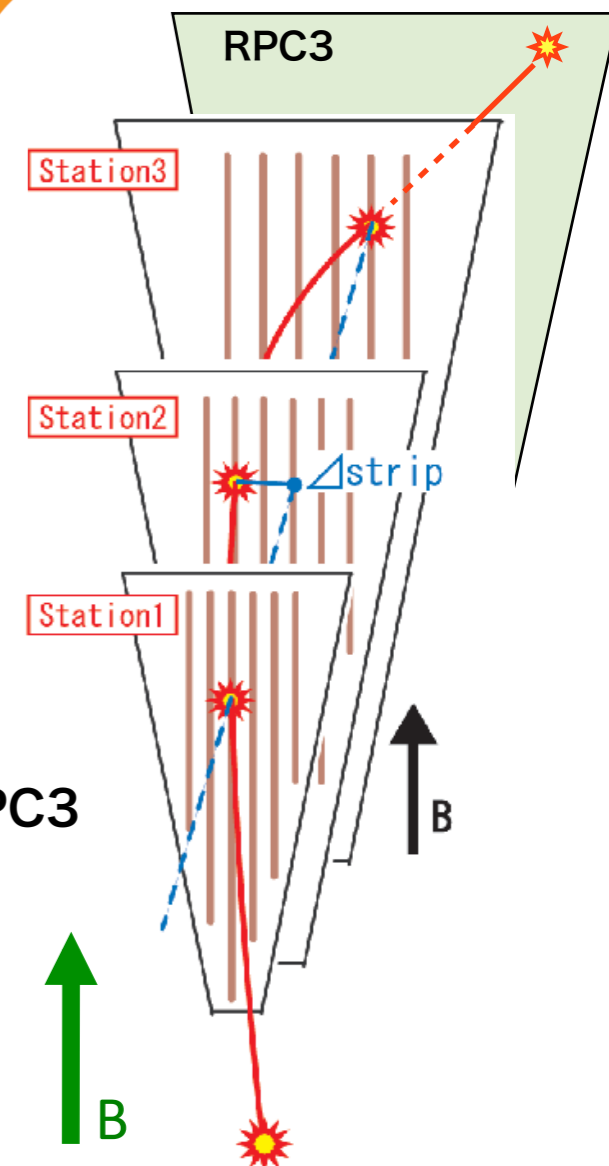


RPC1

2009, 2010



Mutrg



FVTX

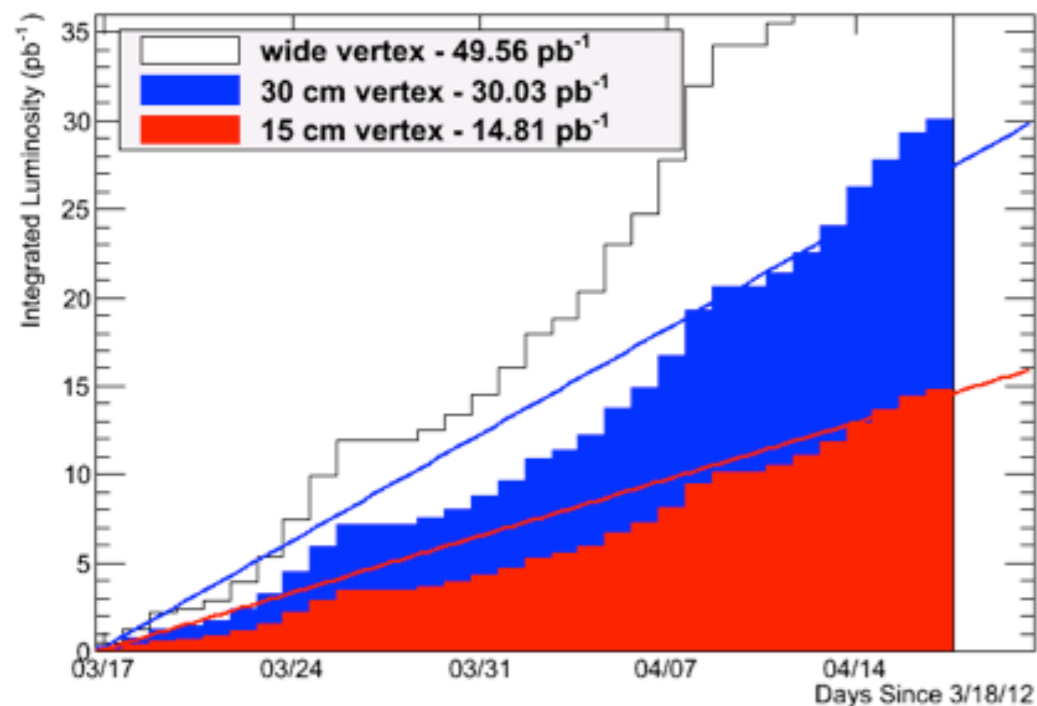
# Muon Arm Upgrade History

Year			2009		2010	2011		2012	
Run Status			pp Run	-	-	pp Run	-	pp Run	-
FWD	MuTrg		install/commissioning			operation / Physics Trigger			
	RPC3	S				install	operation		operation / Physics Trigger
		N		install	commissioning				
	RPC1						install	comm./operation	
	FVTX						install	comm./operation	
CNT	HBD		operation				removed		
	VTX					install	comm.	operation	
W->mu TRG			(MuIDxBBC -- prescaled)			SG1xMuIDxBBC		SG1xRPC3xBBC	
Luminosity   vtx   < 30 cm			8.6		-	16		30	
√s (GeV)			500		-	500		510	

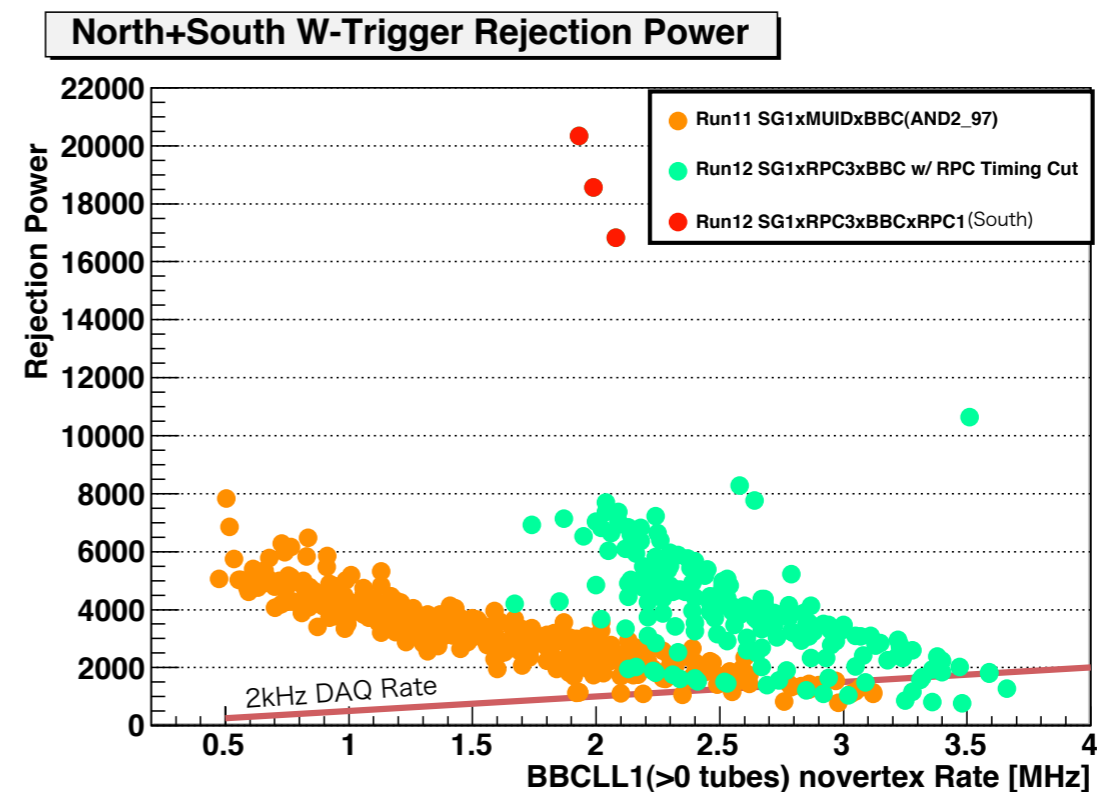
Details of upgrades are spoken  
on Sep 20, S1-V 16:20 by F. Giordano

# Run12 Muon Arm performances

## Run12 $\sqrt{s} = 510$ GeV luminosity history



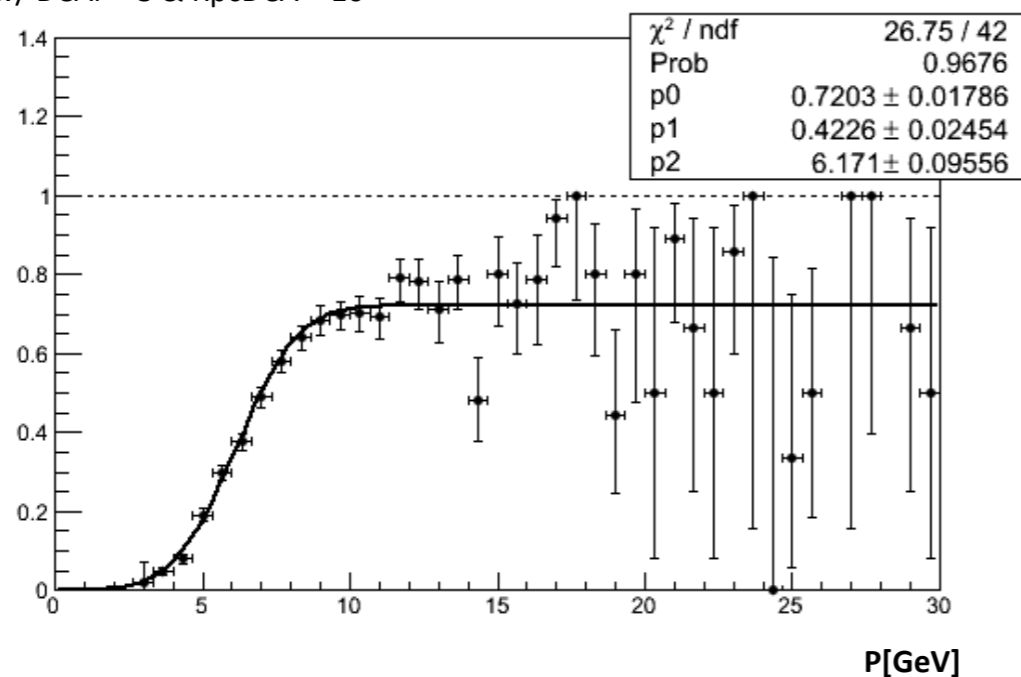
## Trigger Rejection Power



## Run12 $W \rightarrow \mu$ trigger performance

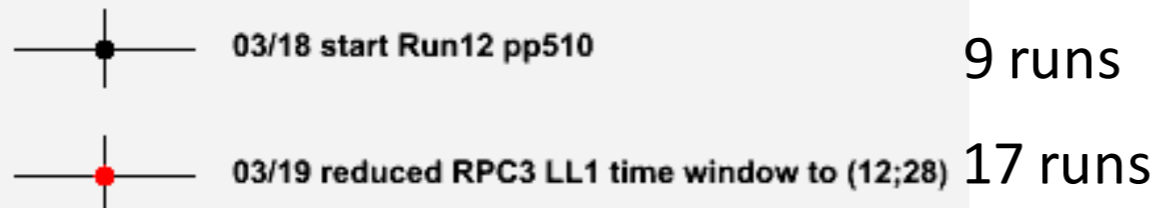
### SG1+RPC3 South

Basic cut w/ DCAr = 3 & RpcDCA = 10

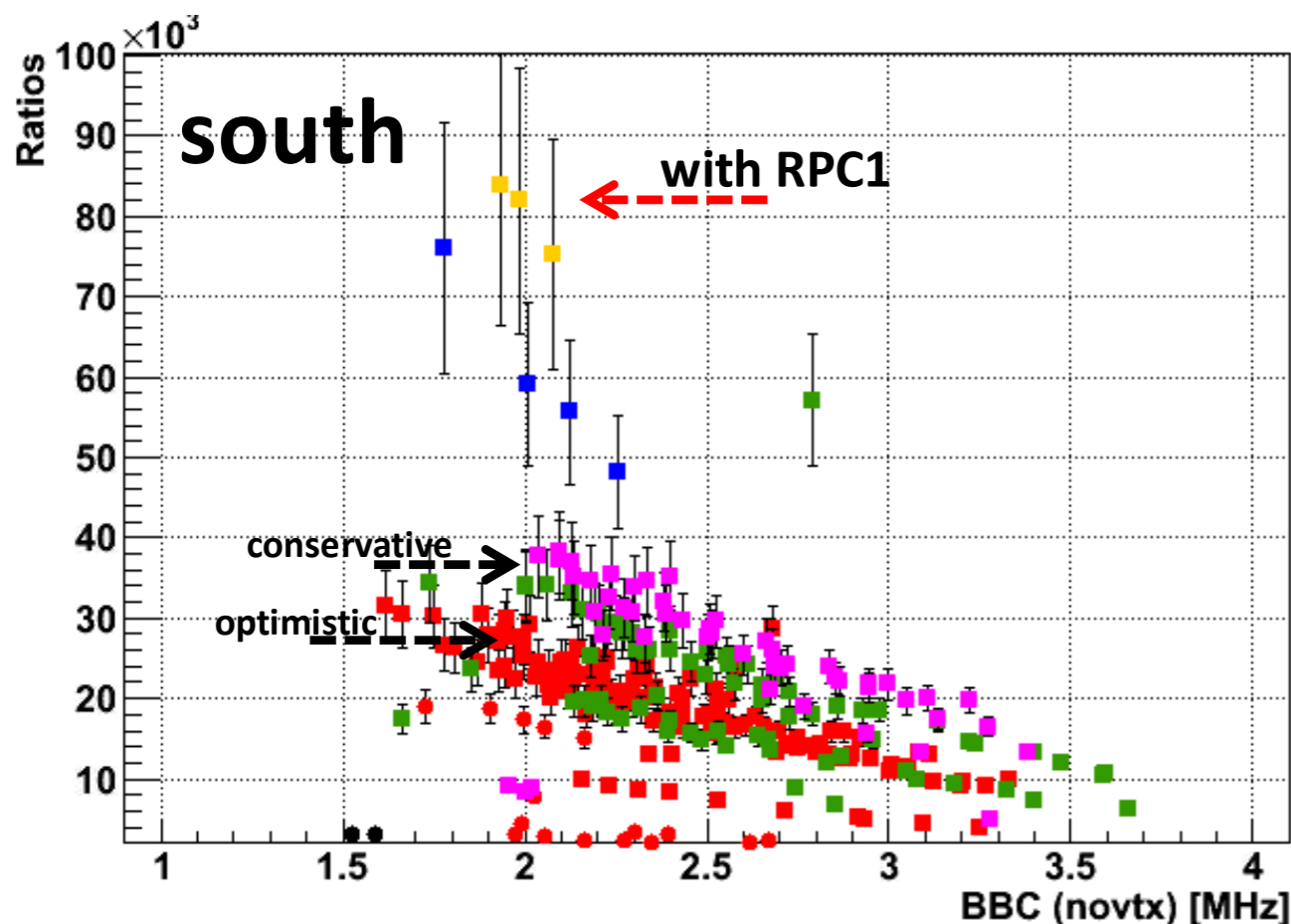
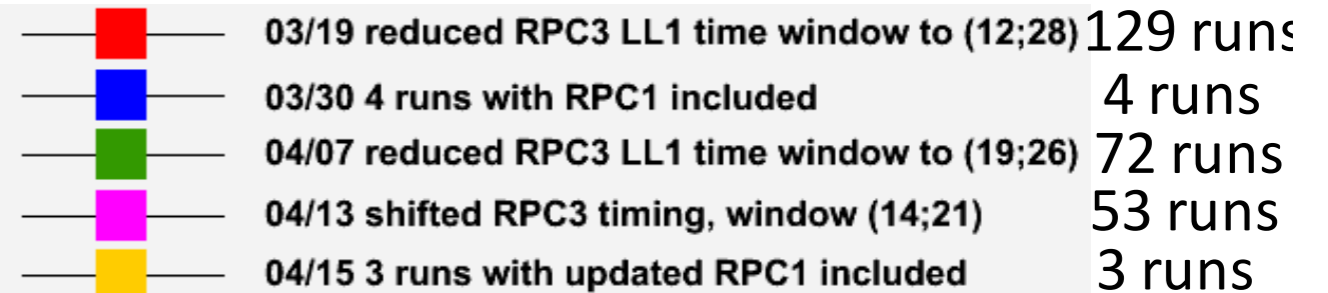


# Prospects of RPC1 for Run13 Muon Trigger

Trigger SG&RPC3:



Trigger SG&RPC3&BBC:



Including RPC1 in W trigger on south @ 2MHz BBC novtx:

- **conservative** rejection gain (considering purple boxes only):

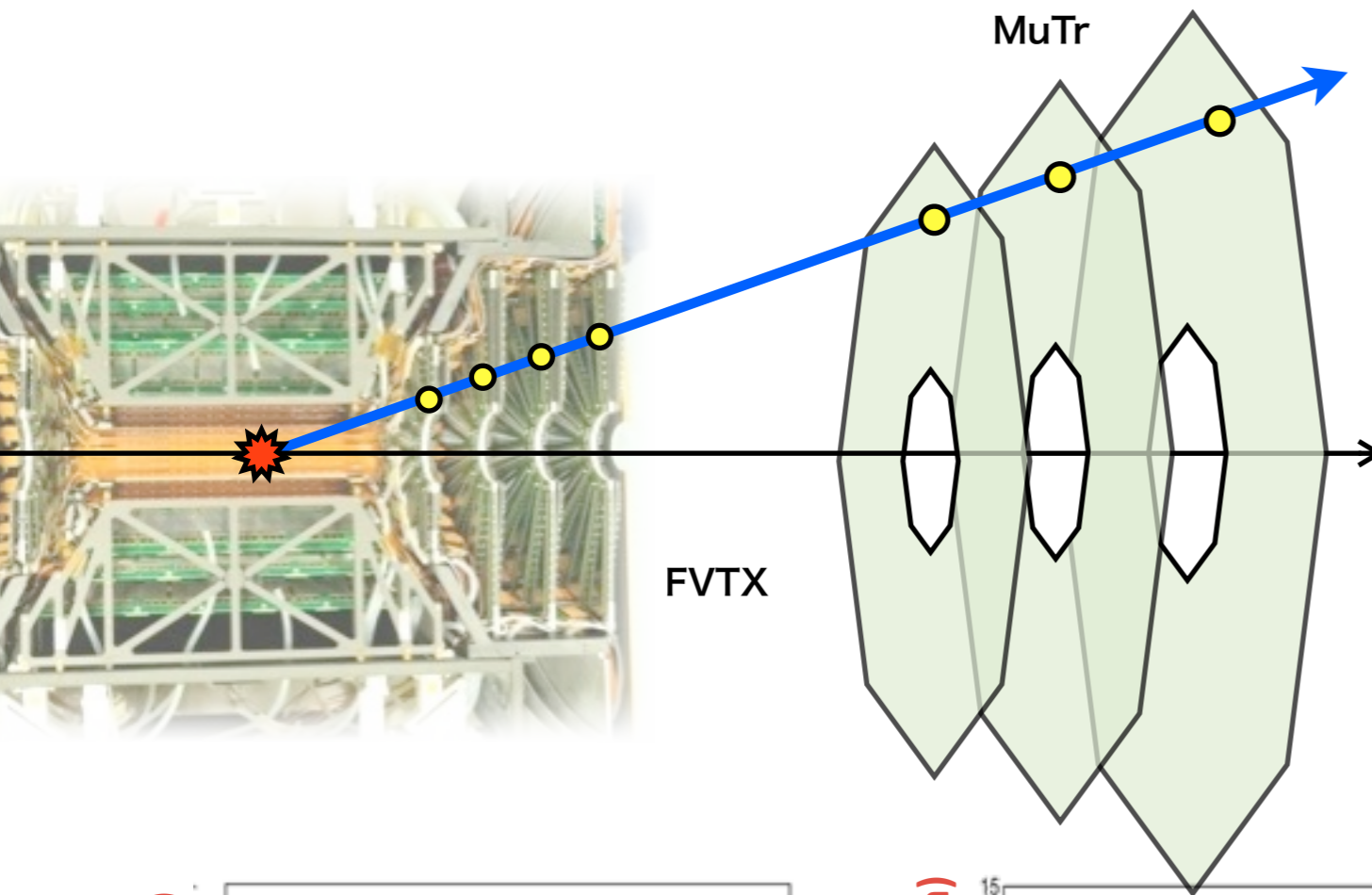
$$82000/36500 = 2.3$$

- **optimistic** rejection gain (considering purple and green boxes):

$$82000/27000 = 3.0$$

We can expect factor 2~3 rejection power increase with including RPC1 to the muon trigger in Run13+.

# Operational of FVTX detector in Run12



Expected to improve analysis power by

- Precise vertex determination
- Better Tracking

